Joint Agency Staff Report on Assembly Bill 8: 2018 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California

California Energy Commission

California Air Resources Board

Edmund G. Brown Jr., Governor
December 2018 | CEC-600-2018-008

California Energy Commission

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ACKNOWLEDGEMENTS

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ABSTRACT

The *Joint Agency Staff Report on Assembly Bill 8: 2018 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California* (2018 Joint Report) is in accordance with Assembly Bill 8 (AB 8) (Perea, Chapter 401, Statutes of 2013). The 2018 Joint Report contains time and cost assessments for the network of publicly available hydrogen refueling stations to support the fuel cell electric vehicle market under the California Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP).

As of December 21, 2018, 38 ARFVTP-funded retail stations selling hydrogen as a transportation fuel to the public, and another 26 stations are in development to become open retail, in California. The ARFVTP funded these 64 stations, which meet nearly two-thirds of the 100-station AB 8 milestone.

California has more than 5,000 fuel cell electric vehicles on its roads, and projections show more than 47,200 fuel cell electric vehicles by 2024 with estimated emissions reductions from these vehicles at nearly 76,000 metric tons of carbon dioxide equivalent by 2024. ARFVTP has invested nearly $120 million, since 2010, to fund and support 64 hydrogen refueling stations to support the increasing FCEV market. The entire remaining hydrogen allocation of $20 million per year through the end of the AB 8 program remains needed to support economies of scale in station design and equipment to reach the 100-station goal by 2024. ARFVTP funding remains necessary to reach the established milestone of designing, constructing, and operating at least 100 hydrogen refueling stations by 2024, and to get on track to possibly reach the goal of 200 stations by 2025 established in 2018 by Governor Edmund G. Brown Jr.'s Executive Order B-48-18.

Keywords: California Energy Commission, California Air Resources Board, Alternative and Renewable Fuel and Vehicle Technology Program, AB 8, hydrogen, hydrogen refueling station, fuel cell electric vehicle, National Renewable Energy Laboratory

Please use the following citation for this report:

Baronas, Jean, Gerhard Achtelik, et al. 2018. *Joint Agency Staff Report on Assembly Bill 8: 2018 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California.* California Energy Commission and California Air Resources Board. Publication Number: CEC-600-2018-008.

ACRONYMS

AB	Assembly Bill
AHJ	Authority having jurisdiction
ANSI	American National Standards Institute
ARFVTP	Alternative and Renewable Fuel and Vehicle Technology Program
BAAQMD	Bay Area Air Quality Management District
CaFCP	California Fuel Cell Partnership
Cap-X	Capital expense
CARB	California Air Resources Board
CDFA	California Department of Food and Agriculture
CEQA	California Environmental Quality Act
CHIT	California Hydrogen Infrastructure Tool
CI	Carbon intensity
CSA	Canadian Standards Association
DMS	CDFA Division of Measurement Standards
DMV	California Department of Motor Vehicles
EER	Energy Economy Ratio
FCEV	Fuel cell electric vehicle
GFO	Grant funding opportunity
GHG	Greenhouse gas
GO-Biz	Governor’s Office of Business and Economic Development
H35	Hydrogen at a pressure of 35 megapascals (MPa), also called 350 bar
H70	Hydrogen at a pressure of 70 megapascals (MPa), also called 700 bar
HGV	Hydrogen gas vehicle and fueling installations
HRI	Hydrogen refueling infrastructure
HSP	Hydrogen Safety Panel
HySCapE	Hydrogen Station Capacity Evaluation
HyStEP	Hydrogen Station Equipment Performance
IGC	Industrial Gas Company
LCFS	Low Carbon Fuel Standard
MJ	Megajoule
MSRC	Mobile Source Air Pollution Reduction Review Committee
NFPA	National Fire Protection Association
NREL	National Renewable Energy Laboratory
O&M	Operation and maintenance
OPR	Governor’s Office of Planning and Research
PNNL	Pacific Northwest National Laboratory
PON	Program opportunity notice
PV	Photovoltaic
RECs	Renewable Energy Certificates
SAE	Society of Automotive Engineers
SB	Senate Bill
SCAQMD	South Coast Air Quality Management District
SMR	Steam methane reformation
SNL	Sandia National Laboratories
U.S. DOE	United States Department of Energy
WECC	Western Electricity Coordinating Council
ZEV	Zero-emission vehicle

TABLE OF CONTENTS

Page

Acknowledgements i

Abstract ii

Acronyms iii

Table of Contents iv

List of Figures v

List of Tables vii

Executive Summary 1

CHAPTER 1: Introduction 7

CHAPTER 2: Coverage and Capacity of the Hydrogen Refueling Station Network 10

CHAPTER 3: Fuel Cell Electric Vehicle Deployment 27

CHAPTER 4: Time Required to Permit and Construct Hydrogen Refueling Stations 29

CHAPTER 5: Amount and Timing of the Growth of the Hydrogen Refueling Network 35

CHAPTER 6: Remaining Cost and Time Required to Establish a Network of 100 Publicly Available Hydrogen Refueling Stations 39

CHAPTER 7: Self-Sufficiency Evaluation of Hydrogen Refueling Stations 48

CHAPTER 8: Conclusions 52

APPENDIX A: Hydrogen Refueling Station Financial Assessment A-1

APPENDIX B: Fueling Trends B-1

APPENDIX C: Self-Sufficiency Survey Vignettes C-1

APPENDIX D: ARFVTP-Funded Stations D-1

APPENDIX E: Hydrogen at Scale Cooperative Research and Development Agreements E-1

APPENDIX F: References F-1

LIST OF FIGURES

Page

Figure 1: Projected Station Openings Through 2024 7

Figure 2: Commissioner Janea Scott With Senator Steven Bradford at the ARFVTP 10-Year Anniversary in Sacramento 8

Figure 3: Commissioner Janea Scott and Energy Commission Staff Celebrating National Hydrogen and Fuel Cell Day in Sacramento 9

Figure 4: Open Retail and Planned Hydrogen Refueling Stations in California 11

Figure 5: Open Retail and Planned Hydrogen Refueling Stations in the San Francisco Bay Area and Greater Los Angeles Area 12

Figure 6: ARFVTP-Funded Hydrogen Production Plants 13

Figure 7: Coverage of Open Retail and Planned Hydrogen Refueling Stations in California 16

Figure 8: Actual Average Hydrogen Dispensing (Daily) 18

Figure 9: The Emeryville Station 20

Figure 10: Actual and Projected CO_2e Emissions Reductions From 64 Funded Stations 23

Figure 11: NO_x Emissions Reductions by Region 24

Figure 12: $PM_{2.5}$ Emissions Reductions by Region 25

Figure 13: FCEV Count Projections 28

Figure 14: Decreased Average Hydrogen Refueling Station Development Times 31

Figure 15: Greater Los Angeles Area Station Network Capacity and Number of Vehicles 36

Figure 16: San Francisco Bay Area Station Network Capacity and Number of Vehicles 36

Figure 17: Sacramento Area Station Network Capacity and Number of Vehicles 37

Figure 18: San Diego Area Station Network Capacity and Number of Vehicles 38

Figure 19: Estimated LCFS Revenue for a 180 kg/day Station With Initial Assumptions 44

Figure 20: Estimated LCFS Revenue for a 1,200 kg/day Station With Initial Assumptions 44

Figure 21: Estimated LCFS Revenue for a 180 kg/day Station With Adjusted Assumptions 45

Figure 22: Estimated LCFS Revenue for a 1,200 kg/day Station With Adjusted Assumptions 46

Figure 23: Industry Survey Responses to Questions About Hypothetical Profitable Stations 50

Figure A-1: Financial Assessment, 200 kg/day Connector/Destination Station A-2

Figure A-2: Financial Assessment, 400 kg/day Gaseous Truck Delivery Station A-3

Figure A-3: Financial Assessment, 600 kg/day Liquid Truck Delivery Station A-4

Figure B-1: Quarterly Hydrogen Station Utilization, H70 and H35 .... B-1

Figure B-2: Number of Stations by Level of Utilization and Quarter B-2

Figure B-3: Percentage of Station-Days by Utilization Rate B-3

Figure B-4: Record Day Dispensing for the UC Irvine Station B-4

Figure B-5: Q4 2017 to Q3 2018 Total Cumulative Dispensing by Time of Day by Region B-4

Figure B-6: Greater Los Angeles Area Q3 2018 Fueling by Time of Day B-5

Figure B-7: San Francisco Bay Area Q3 2018 Fueling by Time of Day B-5

Figure B-8: San Diego Area Q3 2018 Fueling by Time of Day B-5

Figure B-9: Sacramento Area Q3 2018 Fueling by Time of Day B-5

Figure B-10: Q4 2017 to Q3 2018 Fueling Events by Time of Day Compared With Gasoline B-6

Figure B-11: Q4 2017 to Q3 2018 Total Cumulative Dispensing by Day of Week by Region....... B-7

Figure B-12: Q4 2017 to Q3 2018 Fueling Events by Day of Week Compared With Gasoline...... B-7

LIST OF TABLES

Page

Table 1: Hydrogen Refueling Network Capacity 17

Table 2: Stations With the Highest Utilization in One Day (2018 Q3) 18

Table 3: Quarterly Dispensing Statistics 19

Table 4: Critical Milestones for Station Development 29

Table 5: Station Development Phases 30

Table 6: Average Duration of Hydrogen Refueling Station Development Phases 32

Table 7: Regional Projection for the Need for Fuel 35

Table A-1: Summary of Key Financial Metrics for Three Hydrogen Refueling Station Designs .. A-1

Table D-1: 38 ARFVTP-Funded Open Retail Stations D-1

Table D-2: 26 ARFVTP-Funded Planned Stations D-7

EXECUTIVE SUMMARY

The *Joint Agency Staff Report on Assembly Bill 8: 2018 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California* (2018 Joint Report) describes the planning, design, development, and deployment of hydrogen refueling stations critical to supporting the adoption of fuel cell electric vehicles (FCEVs), which are zero-emission vehicles (ZEVs) that reduce greenhouse gas (GHG) emissions. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) directs the California Energy Commission to allocate $20 million annually, not to exceed 20 percent of the funds appropriated by the Legislature, from the Alternative and Renewable Fuel and Vehicle Technology Fund for planning, developing, and deploying hydrogen refueling stations until there are at least 100 publicly available stations in California. The Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP) funds the development of hydrogen refueling stations to support the early FCEV market and the increasing population of on-road FCEVs.

This joint report satisfies an Assembly Bill 8 (AB 8) requirement for the Energy Commission and California Air Resources Board (CARB) to report on the remaining cost and time needed to establish the hydrogen refueling station network. The focus of the agencies' efforts continues to be the development of a hydrogen refueling network that meets varied drivers' needs and enables Californians to adopt FCEV technology seamlessly into their daily lives. Identifying station locations that meet drivers' needs is not a static pursuit, and the agencies leverage analyses performed by the California Hydrogen Infrastructure Tool (CHIT) to identify proposed locations with strong potential to contribute positively to the overall health and utility of the growing hydrogen refueling network in California.

In January 2018, California took action to address climate change by setting new goals for ZEV deployment when Governor Edmund G. Brown Jr. signed Executive Order B-48-18 to direct that all state entities work with the private sector and all appropriate levels of government to put at

KEY TAKEAWAYS

- **This report addresses hydrogen refueling station planning, design, development, and deployment.**
- **AB 8 directs the Energy Commission to allocate $20 million annually from the ARFVTP for hydrogen refueling stations until there are at least 100 stations in California.**
- **The ARFVTP funds the development of hydrogen refueling stations to support the FCEV market.**
- **The Energy Commission and CARB work to develop a station network that meets varied drivers' needs and enables Californians to adopt FCEV technology seamlessly into their daily lives.**

least 5 million ZEVs on California roads by 2030. (This number includes FCEVs and battery electric vehicles.) Executive Order B-48-18 further orders that all state entities work with the private sector and all appropriate levels of government to spur the construction and installation of 200 hydrogen fueling stations and 250,000 zero-emission vehicle chargers, including 10,000 direct current fast chargers, by 2025. Governor Brown set forth the *ZEV Action Plan* in 2013 (updated in 2016 and 2018), which articulates a roadmap toward a goal established in a previous executive order, B-16-12: 1.5 million ZEVs on California's roadways by 2025. This interim goal provides direction for today's ARFVTP activities.

Also this year, CARB approved a package of amendments, or updates, to the Low Carbon Fuel Standard (LCFS) regulation and included a new provision for Hydrogen Refueling Infrastructure (HRI) credit generation. HRI credits offer incentives for accelerated station deployment by providing a relatively assured revenue stream to offset part of the cost of station ownership during the early low-utilization period of the life of a new station.

The HRI provision achieves this by crediting hydrogen station owners for unused station capacity in addition to the LCFS credits station owners can generate for dispensed fuel. Once an HRI project application is approved by CARB, HRI credits may be earned for up to 15 years, allowing hydrogen station owners to reasonably forecast the number of credits, and associated revenue from selling those credits, they can expect over that period. If station throughput is low, HRI credit generation can help make up for low revenues that can make it difficult for station owners to continue operation. As throughput increases with more FCEVs on the road, the station generates fewer HRI credits. The system is, therefore, self-regulating. The overall number of HRI credits that can be generated is also capped to ensure that these credits do not overwhelm the LCFS credit market.

The LCFS update encourages accelerated ZEV infrastructure development in support of the Governor's Executive Order B-48-18. The LCFS update also provides opportunity to augment ARFVTP funds leading to the potential to fund

KEY TAKEAWAYS

- **Executive Order B-48-18 established new goals of 200 stations by 2025 and 5 million ZEVs by 2030 in California.**
- **LCFS HRI credits offer a new incentive to encourage private investment and accelerate station deployment.**
- **HRI credits provide support to station owners if station throughput is low in the early years of operation.**
- **The LCFS update provides opportunity to augment ARFVTP funds, leading to the potential to fund more stations.**
- **The LCFS update supports the ZEV infrastructure goals established by Executive Order B-48-18.**

more stations. Combined with anticipated economies of scale due to station developers' plans to purchase the equipment used in stations in large quantities, the LCFS update positions not only more stations to be built, but allows the continued building of stations beyond AB 8, thereby encouraging station developers to plan for the long term. The LCFS update stands to augment the financial position of today's hydrogen refueling stations and that of future stations.

The California Fuel Cell Partnership, of which the Energy Commission and CARB are members, released *The California Fuel Cell Revolution*, which states, "The California Fuel Cell Partnership is pursuing a network of 1,000 hydrogen stations and a fuel cell vehicle population of up to 1,000,000 vehicles by 2030." These additional commitments to decarbonizing the transportation sector created greater urgency around the work to install hydrogen infrastructure described in this joint report.

The network coverage, or the amount of geographic driving area and reach the stations serve, expanded when seven new ARFVTP-funded and one privately upgraded hydrogen station opened. The network includes 38 ARFVTP-funded open retail stations. The network also includes 1 privately funded open retail station and 26 ARFVTP-funded stations in development.

The total hydrogen refueling station network capacity increased from 15,000 kilograms per day at the end of 2017 to 17,000 kilograms today. This increase in capacity is due to an increase in the nameplate capacity design, from 310 kilograms per day to 500 kilograms per day, for a dozen funded stations. From the funded station network, the estimated greenhouse gas emissions reductions from hydrogen displacing gasoline fueling are nearly 76,000 metric tons of carbon dioxide equivalent (CO_2e) per year by 2024. The Energy Commission is funding one renewable hydrogen production plant and plans to fund a second plant to support coverage and capacity growth of the network, and these should provide the required 33 percent renewable hydrogen required by Senate Bill 1505 (Lowenthal, Chapter 877, Statutes of 2006).

KEY TAKEAWAYS

- **Combined with purchasing station equipment in larger quantities, the LCFS update may help achieve economies of scale.**
- **Hydrogen stakeholders are focused on scaling up infrastructure to meet the longer-term vision of "a network of 1,000 hydrogen stations and a fuel cell vehicle population of up to 1,000,000 vehicles by 2030."**
- **California has 38 ARFVTP-funded open retail stations.**
- **The total daily hydrogen refueling station network capacity increased from 15,000 to 17,000 kilograms in one year.**
- **The estimated greenhouse gas emissions reductions from hydrogen fuel displacing gasoline are nearly 76,000 metric tons of CO_2e per year by 2024.**

CARB reports 5,014 fuel cell electric vehicle (FCEV) registrations in California as of October 2018, based on California Department of Motor Vehicles (DMV) registration data. The number is more than double the 2,473 from October 2017. As a result, the demand for fuel nearly doubled from last year. The latest available FCEV deployment information, from industry sources, is that 5,658 FCEVs have been sold or leased in California as of December 1, 2018.

Based on auto manufacturer surveys, CARB projects 23,600 FCEVs in California by 2021 and 47,200 by 2024. A pathway to 1 million FCEVs by 2030 is not yet defined, but the 2030 vision represents a "pathway to scaling up the market, by leveraging the market-based policy to attract private capital, and activating economies of scale," as noted in the *California Fuel Cell Revolution*. Hydrogen refueling station development time decreased substantively from 2009 to today. The average time spent before station developers filed an initial permit application for the most recently funded stations was almost 85 percent less than the average time spent by developers working on the previously funded group of stations, largely due to the critical milestone requirements.

Today's hydrogen refueling station network of 65 stations provides enough fuel for the existing FCEV population. However, California needs more station coverage and capacity to enable the projected FCEV market growth. The projected FCEVs will need nearly double the current, funded network capacity of 17,000 kilograms per day by 2024. The Energy Commission staff expects to fund at least 100 hydrogen refueling stations by 2024 using the full, remaining ARFVTP funding allocations. The Hydrogen Draft Solicitation Concepts propose strategies that will reduce hydrogen refueling station development costs to meet and exceed the 100-station goal. With the Hydrogen Draft Solicitation Concepts, the Energy Commission staff estimates about 15 stations will become open retail annually, with some reaching completion as early as 2020 and with steady growth from 2022 on. The capacity of the 110 projected open retail stations roughly matches the projection of 47,200 FCEVs by 2024.

KEY TAKEAWAYS

- **As of October 2018, 5,014 FCEVs are registered with the DMV.**
- **There are 5,658 FCEVs sold or leased in California as of December 1, 2018.**
- **CARB projects 47,200 FCEVs in California by 2024.**
- **The time spent before station developers filed an initial permit application decreased substantially due to critical milestone requirements.**
- **By 2024, the station network will need to provide nearly double today's funded fueling capacity.**
- **The full remaining ARFVTP funding allocations will be needed to meet and exceed the 100-station goal by 2024.**

CARB and the Energy Commission are working with industry stakeholders to identify the conditions under which the hydrogen refueling market could be self-sufficient without governmental support. Preliminary indications from an industry survey show refueling stations could potentially be profitable with fueling capacities ranging from 500 kilograms per day to 1,000 kilograms per day, assuming several associated conditions are also satisfied. Given that some of the ARFVTP-funded hydrogen station designs are for 500 kilograms per day of capacity, these stations may potentially reach a point of self-sufficiency if other factors such as station utilization and operating costs are favorable.

In conclusion, California remains on the leading edge of hydrogen infrastructure development for transportation, and public and private partners are working together to keep station development on the right track. At the close of 2018, 39 hydrogen refueling stations, including 1 privately funded, are open to the public, and another 26 stations are funded and in various development stages. Public support and public funding remain necessary to achieve the 100-station goal, and more funding will be needed to support the 200-station goal set by Governor Brown. The ARFVTP shall stay the course working with stakeholders to support today's hydrogen refueling network and that of the future.

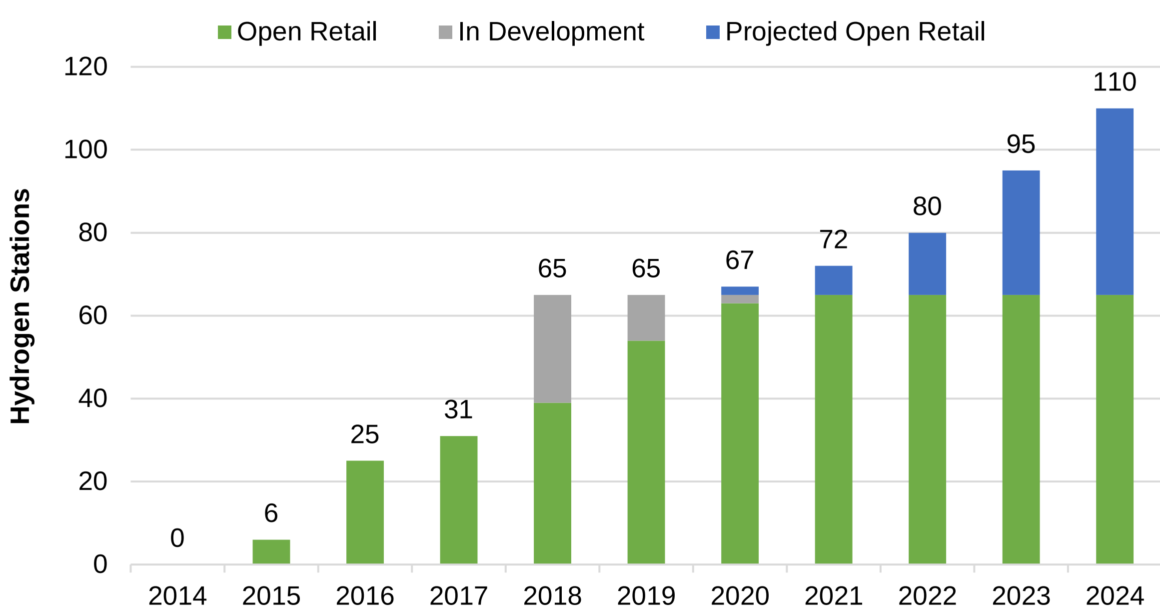
KEY TAKEAWAYS

- **CARB and the Energy Commission are working to identify conditions under which the hydrogen refueling market could be self-sufficient.**
- **The station count is 39 open retail and 26 in various development stages.**
- **Public support and public funding remain necessary to achieve the 100-station goal, and more funding will be needed to support the 200-station goal.**

CHAPTER 1: Introduction

This *Joint Agency Staff Report on Assembly Bill 8: 2018 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California* (2018 Joint Report) reviews the progress of fuel cell electric vehicle (FCEV) deployment and hydrogen refueling stations in California. Based on this review, which includes actual cost data, the 2018 Joint Report determines the entire remaining hydrogen allocation of $20 million per year through the end of the AB 8 program is necessary to support economies of scale in equipment purchases and station designs to develop and open stations "until there are at least 100 publicly available hydrogen-fueling stations in operation in California" (Health and Safety Code § 43018.9[e][1]). Figure 1 shows the projected station openings, which could exceed 100 stations by 2024 and put the state on the path toward 200 stations as called for in Executive Order B-48-18.

Figure 1: Projected Station Openings Through 2024



Source: California Energy Commission

Assembly Bill (AB) 8 (Perea, Chapter 401, Statutes of 2013) directs the California Energy Commission to allocate $20 million annually, not to exceed 20 percent of the amount of funds appropriated by the state Legislature from the Alternative and Renewable Fuel and Vehicle Technology Fund, toward the 100 hydrogen refueling stations. AB 8 reauthorized the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP), created by Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007), until January 1, 2024. AB 8 requires an annual review and reporting by the Energy Commission and the California Air Resources

Board (CARB). The 2018 Joint Report is the fourth such annual report; Appendix F lists the three previous reports.

On January 25, 2018, Governor Edmund G. Brown Jr.'s Executive Order B-48-18 established new goals of achieving 200 hydrogen stations by 2025 and 5 million zero-emission vehicles (ZEVs) in California by 2030.[1] In July 2018, the CaFCP released *The California Fuel Cell Revolution*, which CaFCP members developed collaboratively with a shared vision of achieving demand for one million FCEVs supported by 1,000 stations by 2030 after scale in the network is achieved through leverage of public and private funding.[2]

This year was a milestone year for the ARFVTP. On March 7, 2018, the Energy Commission celebrated the ARFVTP 10-year anniversary at the State Capitol with a public showcase of ARFVTP investments in a variety of successful projects, including the expansion of the state's hydrogen refueling network.

Figure 2 is a photograph taken at the ARFVTP 10-year anniversary celebration.

Figure 2: Commissioner Janea Scott With Senator Steven Bradford at the ARFVTP 10-Year Anniversary in Sacramento

Source: California Energy Commission

In September 2018, Governor Brown hosted the Global Climate Action Summit in San Francisco, where fuel cell technology (including light-duty, heavy-duty, and transit vehicles) were displayed. The summit also was where the Hydrogen Council announced a goal to fully decarbonize hydrogen fuel for transportation by 2030,[3] a call to action that strengthens the potential for FCEVs to reduce greenhouse gas emissions from the transportation sector.

Finally, and importantly, industry stakeholders engaged in CARB's public process (April-September 2018) to update the Low Carbon Fuel Standard (LCFS) regulation to offer greater incentive for zero-emission vehicle (ZEV) infrastructure investment. The Board-approved regulation could go into effect on January 1, 2019, and provide a new potential revenue stream

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1 Executive Order B-48-18 is available at https://www.gov.ca.gov/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/. The Governor's Interagency Working Group on Zero-Emission Vehicles released a *2018 ZEV Action Plan Priorities Update* in response to the executive order. http://business.ca.gov/Portals/0/ZEV/2018-ZEV-Action-Plan-Priorities-Update.pdf.

2 California Fuel Cell Partnership. July 2018. *The California Fuel Cell Revolution: A Vision for Advancing Economic, Social, and Environmental Priorities.* Available at https://cafcp.org/sites/default/files/CAFCR.pdf.

3 The Hydrogen Council is a global initiative of leading energy, transport, and industry companies with a united vision and long-term ambition for hydrogen to foster the energy transition. Information about the Hydrogen Council's 2030 goal is available at http://hydrogencouncil.com/our-2030-goal/.

for hydrogen refueling station owners and accelerate infrastructure construction to support rapid expansion of the FCEV market.

Figure 3: Commissioner Janea Scott and Energy Commission Staff Celebrating National Hydrogen and Fuel Cell Day in Sacramento

Source: California Energy Commission

On October 8, 2018, the Energy Commission celebrated National Hydrogen and Fuel Cell Day. Commissioner Scott and Energy Commission staff walked 1.008 miles (to reflect the atomic weight of hydrogen, 1.00794 µ) around Sacramento's Capitol Park to increase awareness about hydrogen and fuel cell technologies in collaboration with an initiative kicked off by the U.S. Department of Energy (U.S. DOE) Office of Energy Efficiency & Renewable Energy, Fuel Cell Technologies Office.[4]

The ARFVTP relies on valuable input from and collaboration with various sources when planning the hydrogen refueling station network, including:

- State agencies such as CARB, the Governor's Office of Business and Economic Development (GO-Biz), and the California Department of Food and Agriculture, Division of Measurement Standards (CDFA/DMS).
- Regional agencies, including the South Coast Air Quality Management District (SCAQMD) and the Bay Area Air Quality Management District (BAAQMD), which also offer financial support to complete hydrogen stations within their respective jurisdictions. Through 2018, SCAQMD provided more than $14 million, and BAAQMD awarded nearly $2 million.
- Local agencies, including planning, building, and safety officials.
- Experts at U.S. DOE and national laboratories, including the National Renewable Energy Laboratory (NREL) and the Pacific Northwest National Laboratory (PNNL).
- Industry stakeholder groups including the CaFCP, the California Hydrogen Business Council, the Hydrogen Council, SAE International, and the CSA Group.
- Public comments from workshops and dockets, and feedback from FCEV drivers.

With these input, the Energy Commission develops grant solicitations to elicit technically sound and sustainable projects from the most capable experts and companies.

4 More information available at https://www.energy.gov/eere/fuelcells/articles/how-celebrate-hydrogen-and-fuel-cell-day-letter-all-stakeholders.

CHAPTER 2: Coverage and Capacity of the Hydrogen Refueling Station Network

The Hydrogen Refueling Station Network Coverage Expanded

Coverage is a geographical concept that defines how well a station or network of stations provides convenient fueling access throughout the state. To begin understanding the coverage provided by the hydrogen refueling station network, it is necessary to first understand the location of the stations, and these locations are presented in Figures 4 and 5. Among the ARFVTP-funded stations are 38 that are open-retail (retail stations that sell hydrogen as a transportation fuel to the public), 9 of which are in disadvantaged communities. To highlight the spatial relationship among disadvantaged communities and hydrogen stations, Figure 5 shows in dark gray background the locations of disadvantaged communities.

There are 25 stations in development, including 1 mobile refueler that is not represented in the station location maps. There is also one legacy station at California State University, Los Angeles (CSULA), which received capital expense funding from CARB and operation and maintenance (O&M) funding from ARFVTP. The CSULA station is open, and stakeholder discussions about upgrading the station to meet current technical standards are ongoing. Adding CSULA to the 25 in development, 26 stations are in process to become open retail.

The Newport Beach station became open retail with private funds, bringing the open retail station count to 39.[5] The 2017 Joint Report listed 65 ARFVTP-funded stations and, due to 1 station proposed in San Jose (Bernal Road) not proceeding, this joint report updates the number to 64 stations.

Figure 6 presents the locations of ARFVTP-funded hydrogen production plants, two of which will produce 100 percent renewable hydrogen. Figure 6 shows the location of the production plants (funded in 2018)[6] and one existing hydrogen production plant. All these plants have production capacity dedicated to serving public hydrogen refueling stations.

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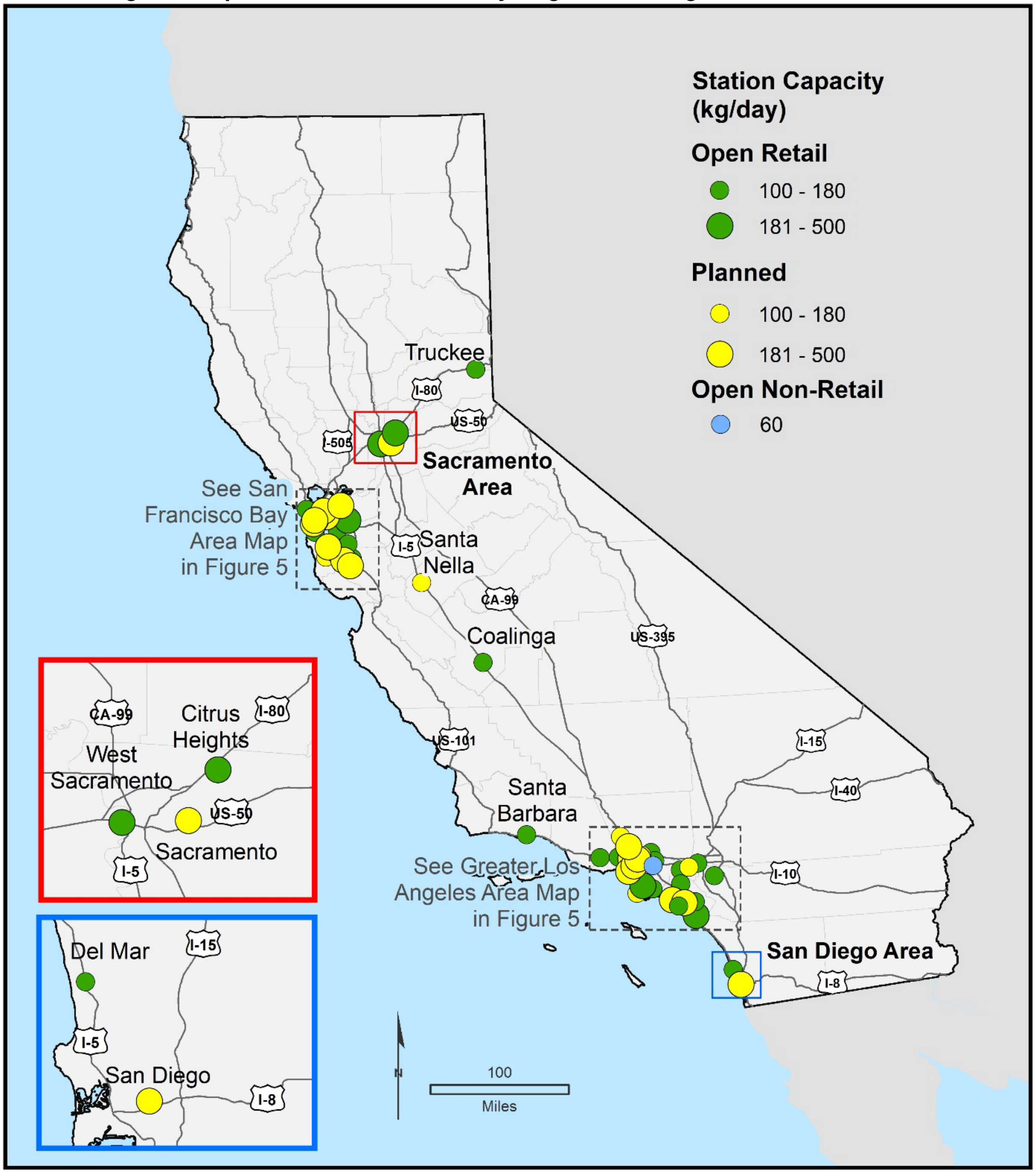
5 Shell opened the Newport Beach hydrogen station in 2012 as one of four demonstration stations rolled-out in Southern California, funded in part by a $1.7 million grant received by the California Air Resources Board. The station uses an onsite steam methane reformer to generate 100 kg/day of hydrogen from natural gas. In 2018, the station was upgraded by Shell from a nonretail station to full open retail status.

This is one of the first hydrogen refueling station upgrades to be funded by private industry. The upgrade includes modernizing the two dispensers to meet the SAE International J2601 (2016) fueling protocol and installing a point-of-sale credit card reader.

The Energy Commission will provide operation and maintenance (O&M) funding for the Newport Beach station.

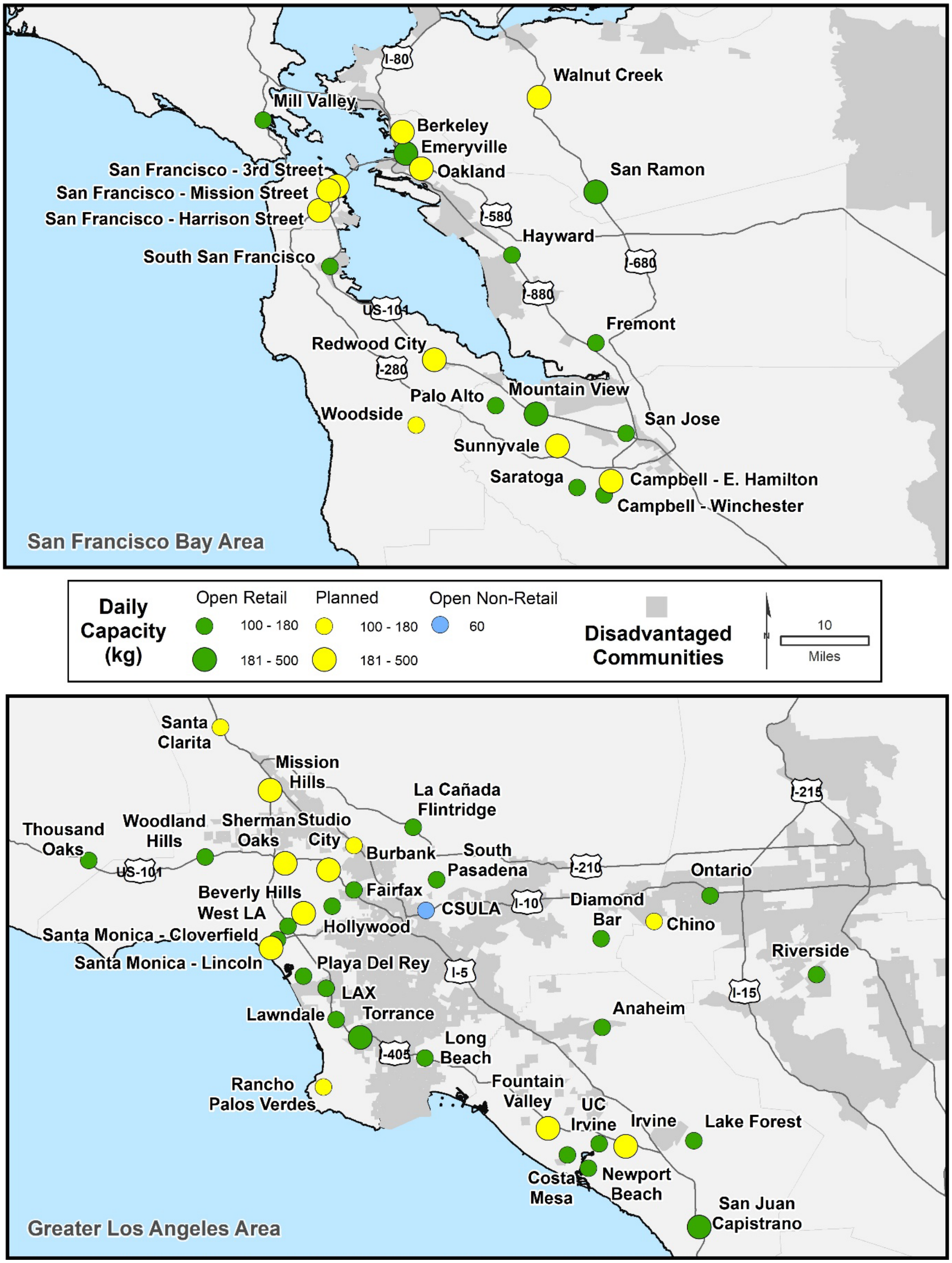
6 One of the funded renewable hydrogen production plants has an executed grant agreement, while the other plant has a proposed award pending Energy Commission approval.

Figure 4: Open Retail and Planned Hydrogen Refueling Stations in California



Source: California Energy Commission

Figure 5: Open Retail and Planned Hydrogen Refueling Stations in the San Francisco Bay Area and Greater Los Angeles Area



Source: California Energy Commission

Figure 6: ARFVTP-Funded Hydrogen Production Plants

Source: California Energy Commission

Consistent with the provisions of Senate Bill (SB) 350: The Clean Energy and Pollution Reduction Act of 2015 (De León, Chapter 547, Statutes of 2015)[7] and CARB's guidance to provide access to clean transportation to individuals in disadvantaged communities,[8] the Energy Commission continues to emphasize the importance of serving disadvantaged communities in its solicitations. CARB's *2018 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development* shows that the hydrogen refueling station network presently covers roughly 35 percent of the disadvantaged community population, including the FCEV traffic that drives through the disadvantaged communities.[9]

In addition, an Energy Commission grant agreement, ARV-17-010 (grant recipient: StratosFuel), funded under GFO-16-605, Innovative Mobility Service Demonstrations with Zero-Emission Vehicles, will implement a car-sharing program called StratosShare.

The StratosShare Pilot Program – Bringing FCEV Technology to Disadvantaged Communities

The StratosShare program will:

- **Offer a public ZEV car sharing service.**
- **Make available 15 FCEVs via an app-based reservation system for rental by the hour, mile, or day.**
- **Launch car sharing in disadvantaged communities in Riverside and San Bernardino Counties, near existing hydrogen refueling stations in Riverside and Ontario.**
- **Provide complimentary insurance and fuel to customers.**
- **Use existing car-sharing platforms to process payments and vet drivers.**
- **Monitor FCEV usage and fueling points to track demand and emissions reduction.**
- **Establish designated, accessible parking.**
- **Plan for geographical and fleet expansion.**

Photo Credit: Marked By Love Photography

7 SB 350 establishes the reduction of greenhouse gases as a state priority through the promotion of various clean energy policies, including widespread transportation electrification. SB 350 information is available at https://www.energy.ca.gov/sb350/.

8 Disadvantaged communities are identified using the California Office of Environmental Health Hazard Assessment's CalEnviroScreen™. Information on CalEnviroScreen is available at https://oehha.ca.gov/calenviroscreen. The CARB guidance is available at https://ww2.arb.ca.gov/sites/default/files/2018-08/sb350_final_guidance_document_022118.pdf.

9 California Air Resources Board. July 2018. *2018 Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development*. https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2018_print.pdf, pp. 16-17.

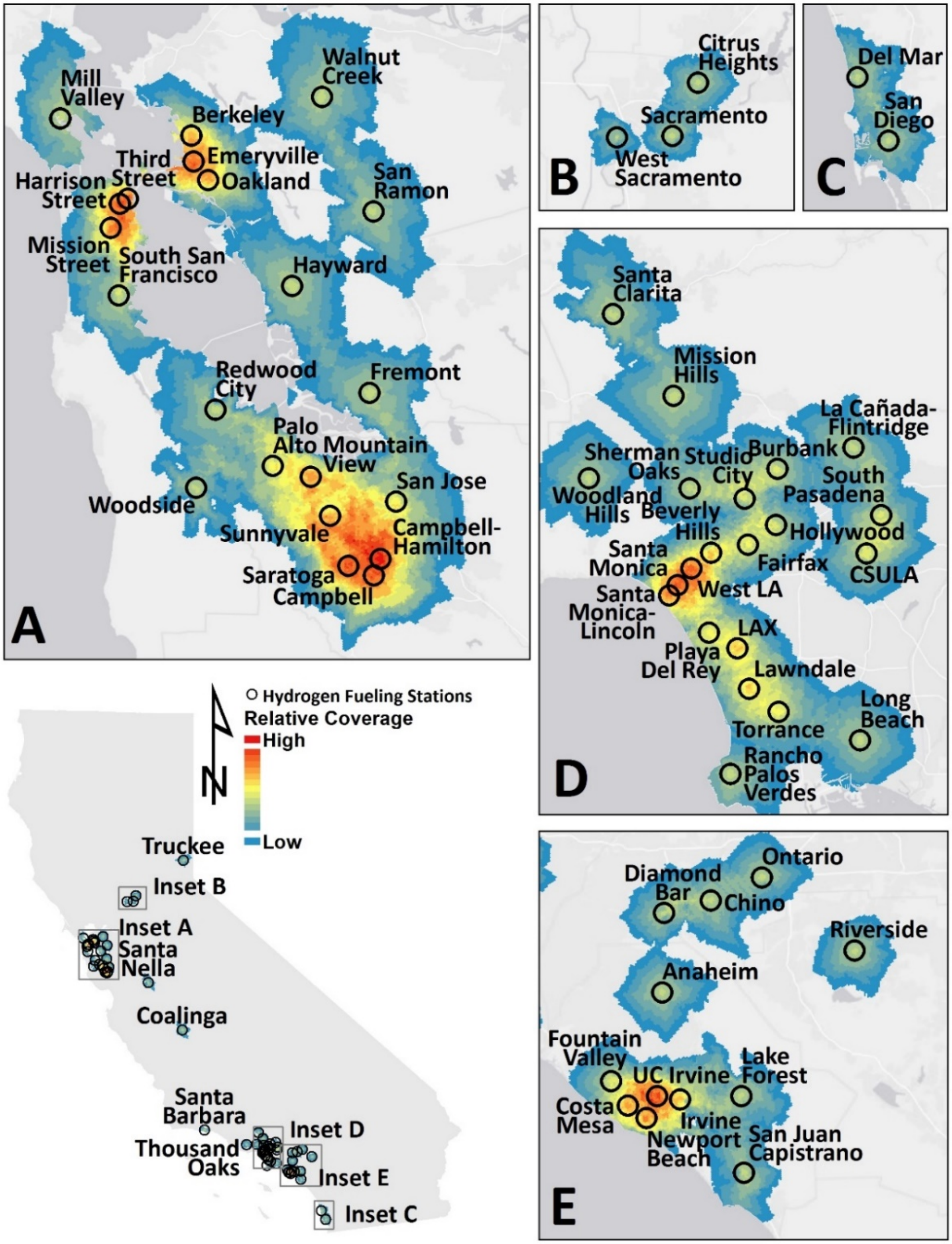
Figure 7 shows the coverage, or the geographic area, served by the network of open retail and planned to become open retail hydrogen refueling stations. Figure 7 was produced by the CARB California Hydrogen Infrastructure Tool (CHIT).[10] In CARB's analysis, coverage provided by a station to an area increases as the distance to a station decreases, and as the number of stations within a convenient driving distance increases. Figure 7 reflects the network coverage by a color scheme, with areas in red having the best coverage, often with multiple stations within a short drive. The blue areas have poor coverage, with a station relatively far away. The CARB analysis considers the areas on the map without color to not have coverage, meaning a hydrogen station is not within a 15-minute drive.

The focus of the Energy Commission and CARB's efforts continues to be the development of a hydrogen refueling network that meets varied drivers' needs and enables Californians to adopt FCEV technology seamlessly into their daily lives. Identifying station locations that meet drivers' needs is not a static pursuit, and the agencies leverage analyses performed by the CHIT to identify proposed locations with strong potential to contribute positively to the overall health and utility of the growing hydrogen refueling network in California.

Most of today's stations rely on hydrogen from the Southern California Fill System in Wilmington in Los Angeles County, which produces up to 4,000 kilograms of hydrogen daily and uses renewable biogas credits for the 33 percent renewable energy requirement. In the future, the stations will have access to 100 percent renewable hydrogen produced by two plants funded under GFO-17-602 in 2018, one of which is under an Energy Commission agreement. The other plant remains to be presented at an Energy Commission Business Meeting. The plants, located in Moreno Valley in Riverside County and in unincorporated Kings County near Coalinga, will make up to 3,000 kilograms of 100 percent renewable hydrogen available to the state's hydrogen station network.

10 Information on CHIT is available at https://www.arb.ca.gov/msprog/zevprog/hydrogen/h2fueling.htm.

Figure 7: Coverage of Open Retail and Planned Hydrogen Refueling Stations in California



Source: CARB

The Capacity of the Hydrogen Refueling Network Increased

The total fueling capacity of the hydrogen refueling network increased in 2018; the sum of the capacity of each station reaches nearly 17,000 kilograms per day. Based on 0.7 kilograms per FCEV per day,[11] the capacity is enough to support up to 24,000 FCEVs, although this number can vary depending on actual FCEV geographical deployment relative to station locations and FCEV driver habits. This is why station location matters. The network frontloading strategy, meaning station deployment prior to FCEV release, reflects the imperative in the *ZEV Action Plan.*[12]

Table 1: Hydrogen Refueling Network Capacity

	Northern California		**Southern California**		**Connector/Destination**	
	Station Quantity	Nameplate Capacity (kg/day)	Station Quantity	Nameplate Capacity (kg/day)	Station Quantity	Nameplate Capacity (kg/day)
Open Retail Stations	13	3,200	23	4,090	3	600
Planned Stations	11	4,300	13	4,620	2	200
Totals	**24**	**7,500**	**36**	**8,700**	**5**	**800**

Source: California Energy Commission

The network capacity increased in 2018 when a station developer transitioned 12 in-development station designs (funded under GFO-15-605) from gaseous hydrogen to liquid hydrogen delivery and storage. This transition increased the fueling capacity for those particular stations from 310 to 500 kilograms per day. The overall network fueling capacity changed from nearly 15,000 kilograms per day to nearly 17,000 kilograms per day.

Figure 8 shows the increased hydrogen dispensing in urban regions[13] and in the connector/destination stations (Coalinga, Santa Barbara, and Truckee), with the demand for fuel increasing most in the San Francisco and Los Angeles areas. This increase in demand reflects FCEV adoption and effective siting of hydrogen refueling stations. The actual hydrogen dispensed differs for many stations from the station nameplate capacity due to throughput remaining below what the station can dispense or, conversely, because demand for fuel at a

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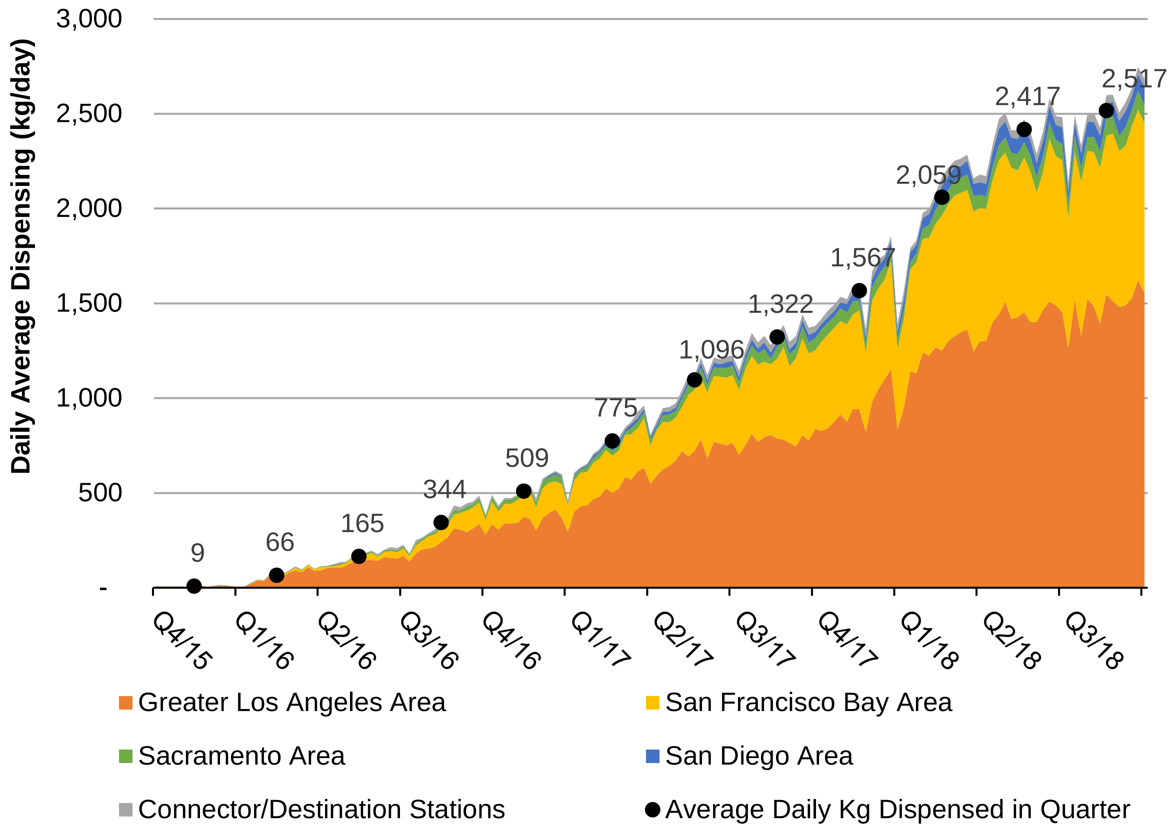
11 Pratt, Joseph, Danny Terlip, Chris Ainscough, Jennifer Kurtz, and Amgad Elgowainy. National Renewable Energy Laboratory and Sandia National Laboratories, 2015. *H2FIRST Reference Station Design Task, Project Deliverable 2-2.* http://www.osti.gov/scitech/servlets/purl/1215215. The privately funded Newport Beach station is included in this tally.

12 The *ZEV Action Plan* identifies fueling infrastructure needs. The *ZEV Action Plan* is available at http://business.ca.gov/ZEV-Action-Plan.

13 The San Francisco Bay Area is defined as Alameda, Contra Costa, Marin, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma Counties. The Greater Los Angeles Area is defined as Los Angeles, Orange, Riverside, San Bernardino, and Ventura Counties. The San Diego Area is defined as San Diego County. The Sacramento Area is defined as El Dorado, Placer, Sacramento, and Yolo Counties.

station exceeds the station characteristics, and more than one truck delivery of hydrogen per day is needed to accommodate the demand.

Figure 8: Actual Average Hydrogen Dispensing (Daily)



Source: California Energy Commission

Table 2 shows stations with the most dispensed hydrogen in a day. The Anaheim station capacity (180 kilograms) is based on recent verbal reports, whereas 100 kilograms as stipulated in the Energy Commission agreement (ARV-12-062) is used elsewhere in this joint report.

Table 2: Stations With the Highest Utilization in One Day (2018 Q3)

Station Name	Reported Nameplate Capacity (kg/day)	Most Dispensed Hydrogen in One Day (kg/day)
UC Irvine	180	320
Diamond Bar	180	288
Anaheim	180	270
Costa Mesa	180	226
Lake Forest	180	202

Source: California Energy Commission

Table 3 reports quarterly dispensing statistics based on the amount of hydrogen dispensed throughout the network and the sales-weighted price[14] of hydrogen per kilogram. The table shows that the amount of fuel dispensed, the number of fueling events, and station utilization (FCEV drivers use these stations to obtain hydrogen) have steadily increased each quarter since the beginning of 2017. The average fueling quantity per transaction at each station has stabilized since it increased significantly from 2.6 kilograms in the first quarter of 2016 (reported in the 2017 Joint Report).

Table 3: Quarterly Dispensing Statistics

Quarterly statistics	Q1/17	Q2/17	Q3/17	Q4/17	Q1/18	Q2/18	Q3/18	Q4/17-Q3/18 average or total
Number of open retail stations	26	28	31	31	33	35	35	35
% change over previous quarter	+4%	+8%	+11%	-	+6%	+6%	-	
Average retail price of hydrogen ($/kg)	$ 15.72	$ 15.42	$ 15.93	$ 16.15	$ 16.18	$ 16.17	$ 16.30	$ 16.21
Range of retail prices ($/kg)	$9.99-$16.78	$9.99-$16.78	$9.99-$16.89	$14.99-$16.78	$14.99-$16.78	$14.99-$16.78	$14.99-$17.99	
% change over previous quarter	+0%	-2%	+3%	+1%	+0%	-0%	+1%	
Average daily hydrogen sold (kg/day)	776	1,093	1,291	1,564	2,033	2,430	2,517	2,136
% change over previous quarter	+50%	+41%	+18%	+21%	+30%	+20%	+4%	
Average station capacity utilization (%)	15.9%	21.4%	22.7%	25.9%	33.1%	36.6%	37.8%	33.4%
% change over previous quarter	+39%	+34%	+6%	+14%	+27%	+11%	+3%	
Total number of fueling events	22,837	31,493	38,089	45,192	57,114	70,095	76,288	248,689
% change over previous quarter	+46%	+38%	+21%	+19%	+26%	+23%	+9%	
Total hydrogen dispensed (kg)	69,512	98,259	117,749	142,571	181,073	219,530	229,097	772,271
% change over previous quarter	+47%	+41%	+20%	+21%	+27%	+21%	+4%	
Average fueling quantity (kg/sale)	3.0	3.1	3.1	3.2	3.2	3.1	3.0	3.1
% change over previous quarter	+0%	+3%	-1%	+2%	+0%	-1%	-4%	

Source: NREL

14 The sales-weighted price is the total revenue from sales, in dollars, divided by the total kilograms of hydrogen sold.

Renewable Hydrogen Production Will Increase

As stipulated in many Energy Commission hydrogen solicitations and grant agreements and per the intent of Senate Bill 1505 (Lowenthal, Chapter 877, Statutes of 2006),[15] the California station network meets a 33 percent renewable hydrogen standard for dispensed hydrogen. The fulfillment can be either in the form of Renewable Energy Certificates (RECs) or from the dispensing of renewable hydrogen produced directly from renewable sources.[16]

Figure 9: The Emeryville Station

Source: Linde

The Emeryville station, shown in Figure 9, uses a 510 kilowatt solar photovoltaic system to provide direct 100 percent renewable electricity to an on-site electrolyzer that is capable of producing up to 65 kilograms per day of renewable hydrogen. The 510 kilowatts of on-site solar generated electricity are enough to produce up to 10 kilograms per day of 100 percent renewable hydrogen, with the balance produced by using RECs for renewable electricity supplied through the grid within the Western Electricity Coordinating Council (WECC).[17]

Other stations using electrolyzers or planning to use electrolyzers are in Chino, Riverside, Ontario, and Woodside. Some will use a combination of on-site electrolyzer-produced hydrogen and delivered hydrogen. Most other hydrogen refueling stations in the network receive hydrogen delivered from the Southern California Fill System in Wilmington that satisfies the 33 percent renewable hydrogen requirement.

New renewable hydrogen production plants, which stand to shore up the amount of directly produced renewable hydrogen available for use by the ARFVTP-funded hydrogen stations, will be designed, built, and commissioned in the near future. These include a 100 percent renewable hydrogen production plant, funded under GFO 17-602, Renewable Hydrogen Transportation Fuel Production Facilities and Systems, with StratosFuel, Inc. The agreement funds a plant in the city of Moreno Valley (Riverside County). The project is named the "Zero Impact Production Facility" and will add 2,000 kilograms of renewable hydrogen to the network per day to a 3,000-kilogram-per-day plant already in development. This project was funded through the ARFVTP

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15 Senate Bill 1505 is available at https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=200520060SB1505.

16 GFO-15-605, Section VII. Renewable Hydrogen Requirements, pp 45-47.

17 The Western Electricity Coordinating Council is the regional entity responsible for promoting bulk electric system reliability for the Western Interconnection, a geographic area that includes 14 western states, as well as some territory in Canada and Mexico. WECC is responsible for compliance monitoring and enforcement of regional renewable energy generation. More information is available at https://www.wecc.biz/Pages/home.aspx.

"Emerging Opportunities" activity and did not use any of the $20 million allocation for hydrogen refueling infrastructure.

A second renewable hydrogen production plant will be constructed and operated by H2B2 USA LLC, pending approval at the Energy Commission Business Meeting in 2019. The project is called the "Solar PV Hydrogen Production Plant in Central California."[18] This H2B2 project will construct a 1,000-kilogram-per-day hydrogen production plant in Kings County, also using renewable electricity from solar PV to make hydrogen. The project site is in an area with multiple large-scale solar PV installations and has the potential to support hydrogen fueling expansion in Central California, as well as urban areas to the north and south. The location, therefore, provides the potential to serve the entire station network, as it exists today. The H2B2 project is funded through the ARFVTP Advanced Fuel Production "Low-Carbon Fuel Production and Supply" activity and does not use any of the $20 million allocated to hydrogen refueling infrastructure.[19]

Renewable Hydrogen Roadmaps

The potential strategies for renewable hydrogen production and the economic and environmental benefits of using the fuel are described in two new roadmaps. Specifically, Energy Independence Now (EIN) published its *Renewable Hydrogen Roadmap*[20] in 2018, and the University of California, Irvine (UCI), California Renewable Hydrogen Deployment Road Map is in process.[21]

Another project using renewable hydrogen is "Renewable Hydrogen Fueling at Scale for Freight" (H2Freight), awarded to Equilon Enterprises LLC, d.b.a. Shell Oil Products U.S. The award funded under GFO-17-603, Advanced Freight Vehicle Infrastructure Deployment, is $8 million to develop, with project partners Toyota Motor North America and FuelCell Energy, a 1,270-kilogram-per-day hydrogen refueling station servicing and promoting the expansion of zero-emission fuel cell electric Class 8 drayage trucks at the Port of Long Beach. This project will produce hydrogen from renewable biogas sourced from California agricultural waste using trigeneration, which will generate water and electricity in addition to hydrogen.[22]

The "Renewable Hydrogen Fueling at Scale for Freight" station will handle refueling for 10 Toyota fuel cell drayage trucks, performing fills of 30+ kilograms. The project is funded

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18 Revised notice of proposed award issued on October 8, 2018, is available at https://www.energy.ca.gov/contracts/GFO-17-602_NOPA_revised.pdf.

19 ARFVTP Investment Plans, which describe the funding categories and activities, are available at https://www.energy.ca.gov/transportation/arfvtp/investmentplans.html.

20 The report is available at https://einow.org/rh2roadmap.

21 Energy Commission Contract 600-17-008 with the UCI Advanced Power and Energy Program will develop a California Renewable Hydrogen Deployment Road Map 2019 through 2050.

22 A similar project, supporting fuel cell trucks at the Port of Los Angeles and large-capacity hydrogen refueling stations in Wilmington and Ontario, is being funded through CARB's Zero and Near Zero Emission Freight Facility program. More information is available at https://ww2.arb.ca.gov/news/carb-announces-more-200-million-new-funding-clean-freight-transportation.

through the ARFVTP category “Advanced Technology Vehicle Support” and the “Advanced Freight and Fleet Technologies” funding activity.[23]

Emissions Reductions Increase When More FCEVs Are Driven

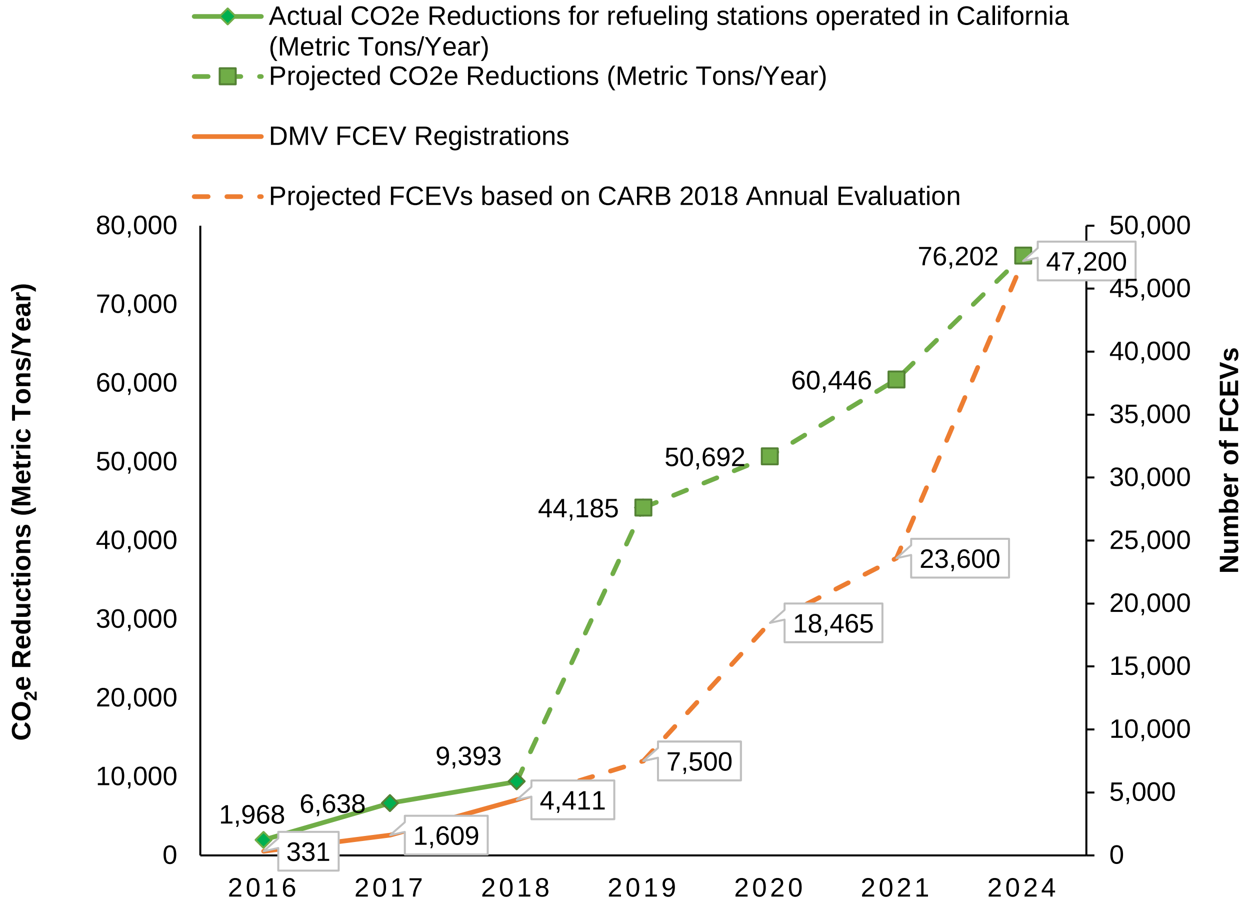
Hydrogen refueling stations contribute to emissions reductions in greenhouse gases (GHGs), oxides of nitrogen (NO_x), and particulate matter 2.5 ($PM_{2.5}$).[24] Figure 10 shows carbon dioxide equivalent (CO_2e) emissions reductions to describe GHG emissions reductions from dispensed hydrogen. The reductions represent the difference between the emissions from producing and distributing gasoline and consuming that gasoline in a “baseline” gasoline vehicle, and the emissions from producing and distributing hydrogen and consuming that hydrogen in an FCEV. The calculations apply the carbon intensity (CI) of hydrogen and gasoline based on the LCFS methods for determining CO_2e emissions reductions.[25] The estimated reductions in Figures 10 - 12 are based on the projected number of FCEVs in CARB’s 2018 Annual Evaluation, with the projected hydrogen demand limited to the nameplate capacity of the 64 funded stations. The actual emissions reductions from the increased number of FCEVs in 2024 will be greater as the number of stations in the network increases.

23 ARFVTP Investment Plans, which describe the funding categories and activities, are available at https://www.energy.ca.gov/transportation/arfvtp/investmentplans.html.

24 *Particulate matter 2.5* is fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller. Source: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics.

25 The calculations use the 2018 LCFS Final Regulation Order available at https://www.arb.ca.gov/regact/2018/lcfs18/lcfs18.htm.

Figure 10: Actual and Projected CO_2e Emissions Reductions From 64 Funded Stations



Source: California Energy Commission

The use of light-duty FCEVs instead of gasoline vehicles results in criteria air pollutant emissions reductions. Staff estimated NO_x and $PM_{2.5}$ emissions reductions using:

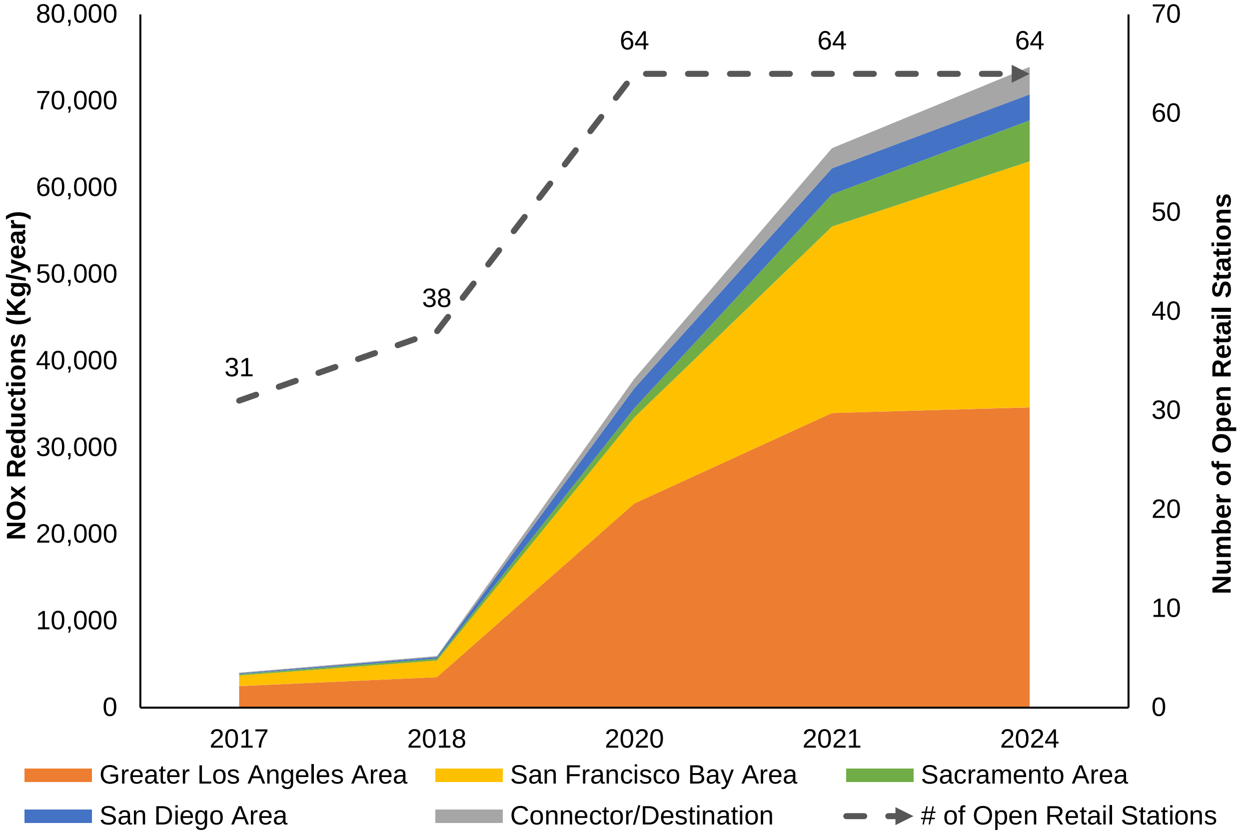
- The fuel economy of 74 miles per gallon gasoline equivalent (mpgge) for the light-duty FCEV and 25 miles per gallon (mpg) for the gasoline vehicle.[26]
- The well-to-wheel emissions of 0.106 g NO_x/mile and 0.0140 g $PM_{2.5}$/mile for the light-duty FCEV and 0.279 g NO_x/mile and 0.0196 g $PM_{2.5}$/mile for the gasoline vehicle.[27]

Figures 11 and 12 show the NO_x and $PM_{2.5}$ emissions reductions projected to 2024 that result from driving zero-emission FCEVs instead of gasoline vehicles. Although the amount of NO_x and $PM_{2.5}$ avoided in the regions is relatively modest, the future impacts could be substantive.

26 https://www.arb.ca.gov/fuels/lcfs/030409lcfs_isor_vol2.pdf.

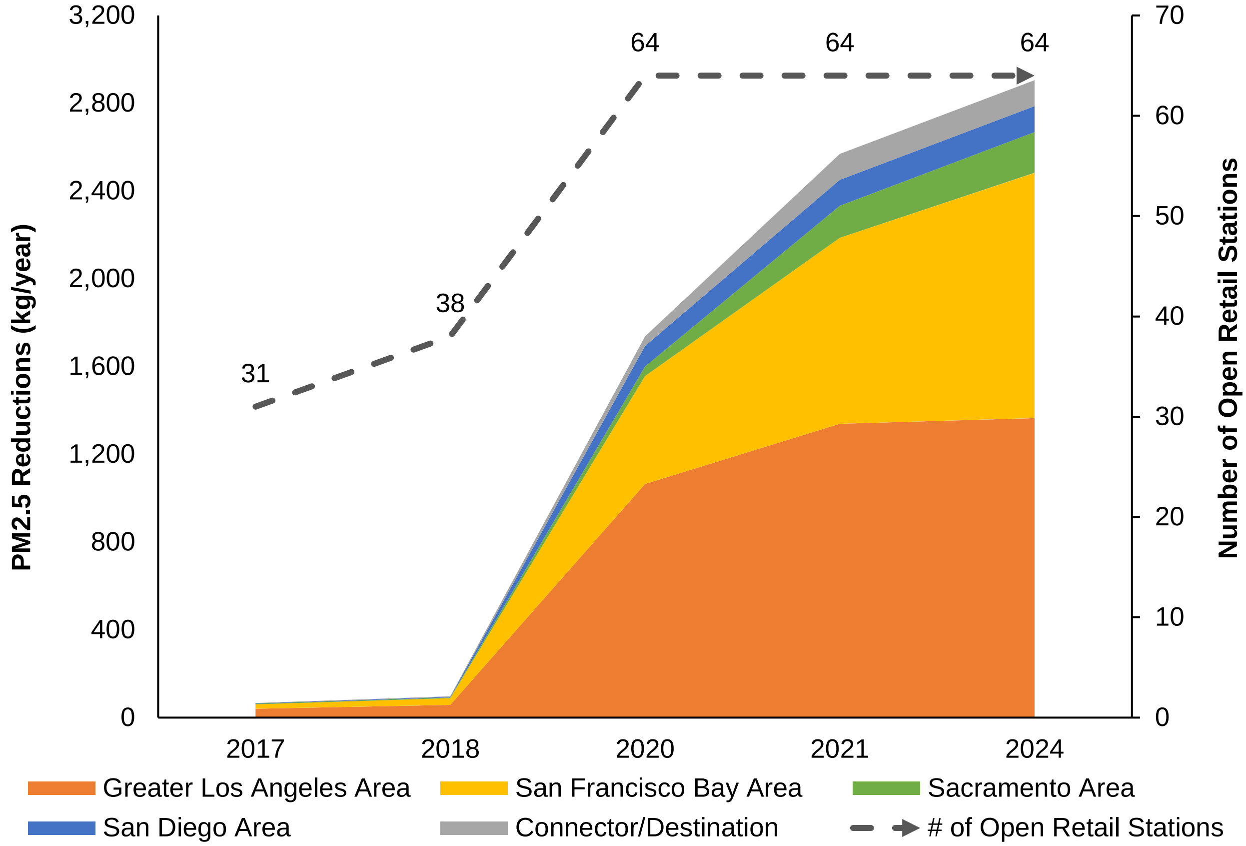
27 The emissions reductions account for oil refinement in the production of gasoline and the associated use in the gasoline automobile, the manufacture of hydrogen through steam methane reformation, and a few electrolyzer stations within the network. Elgowainy, A., et al. 2017. *Life-Cycle Analysis of Air Pollutants Emission for Refinery and Hydrogen Production from SMR.* Argonne National Laboratory. pp 22-24. https://www.hydrogen.energy.gov/pdfs/review17/sa066_elgowainy_2017_o.pdf.

Figure 11: NO_x Emissions Reductions by Region



Source: California Energy Commission

Figure 12: PM2.5 Emissions Reductions by Region



Source: California Energy Commission

Lighting and Signage Are Important to the Stations

The hydrogen stations provide a refueling process that strives to be comparable to or better than drivers' experience with gasoline fueling. Maintaining high-quality customer experience at the hydrogen refueling stations remains especially important when building acceptance and promoting expansion of the hydrogen refueling network and FCEV markets. Factors contributing to customer experience include station lighting and signage. FCEV drivers need adequate lighting while fueling, especially in the dark, and they need signs for directions and information. California codes require lighting at hydrogen refueling stations to meet technical standards. Local authorities having jurisdiction (AHJs) often require lighting installations to pass inspection.[28]

The most recent hydrogen funding solicitation, GFO-15-605, requires on-site signage that explains how hydrogen refueling works. GFO-15-605 also encourages the station developer to initiate discussions with the AHJ, which determines the requirements for trailblazer signs that

28 California Energy Commission. June 2015. *2016 Building Energy Efficiency Standards for Residential and Nonresidential Buildings*. Publication Number: CEC-400-2015-037-CMF. https://www.energy.ca.gov/2015publications/CEC-400-2015-037/CEC-400-2015-037-CMF.pdf.

are guides with directional information and maneuvers from main roadways or ramps to a refueling station. The station developers identify desirable trailblazer sign locations and work with the AHJ to agree on the final location, design, and installation.

The most recent hydrogen funding solicitation, GFO-15-605, also encourages station developers to work with the California Department of Transportation (Caltrans), which determines the requirements for signage on the state highway system as described in the *California Manual on Uniform Traffic Control Devices*[29] and the Caltrans Traffic Operations Policy Directive (13-01).[30] The Caltrans Plug-In Electric Vehicle Charging Station and Hydrogen Fuel Cell Electric Vehicle Fueling Station Signage Fact Sheet[31] recommends that hydrogen station developers first coordinate their trailblazer signs with the AHJ and then work with the regional Caltrans sign district coordinator on the highway signs.

Currently, 32 of the 38 ARFVTP-funded open retail stations receive lighting either from under the normal gasoline refueling canopy or a dedicated lighting structure. Others continue to work with their AHJs for appropriate lighting.

Refueling instructions are available on-site at open retail stations, and most developers are planning or requesting and coordinating trailblazer signage with AHJs and highway signage with Caltrans. Examples of installed highway signage are near the Coalinga and UC Irvine hydrogen refueling stations. The Energy Commission expects to continue requiring lighting and signage in future solicitations.

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29 The California MUTCD is available at http://www.dot.ca.gov/trafficops/camutcd/.

30 The directive is available at http://www.dot.ca.gov/trafficops/policy/13-01.pdf.

31 The signage fact sheet is available at http://www.dot.ca.gov/hq/tpp/offices/orip/pev/2018-09-17SignageFactSheetFINAL.pdf.

CHAPTER 3: Fuel Cell Electric Vehicle Deployment

Both CARB and the Energy Commission assess the potential growth of FCEV adoption, for different purposes. AB 8 requires CARB to collect, aggregate, and report the number of FCEVs to evaluate the need for additional hydrogen refueling stations. To meet this requirement, CARB surveys auto manufacturers on their FCEV production plans for the near future. To plan for longer-term transportation energy needs, the Energy Commission uses 2017 consumer surveys to forecast demand for light-duty FCEV.[32] In the longer term, the Energy Commission's forecasts indicate a larger FCEV adoption than CARB's survey. Both CARB's FCEV projections and the Energy Commission's forecast anticipate rapid growth in the rollout of FCEVs.

The 2018 Joint Report uses the CARB FCEV projections for analyses throughout the report. Figure 13 updates CARB's 2018 Annual Evaluation with the California Department of Motor Vehicles (DMV) 5,014 FCEV registrations as of October 2018. Industry reports that 5,658 FCEVs have been sold or leased in California as of December 1, 2018,[33] the most recent available data as of this report publication. CARB's most recent FCEV projections, based on an auto manufacturer survey, are 23,600 FCEVs by 2021 and 47,200 FCEVs by 2024. These projections indicate a greater confidence in the FCEV market from auto manufacturers compared to last year's CARB survey results of 13,400 FCEVs by 2020 and 37,400 FCEVs by 2023.[34]

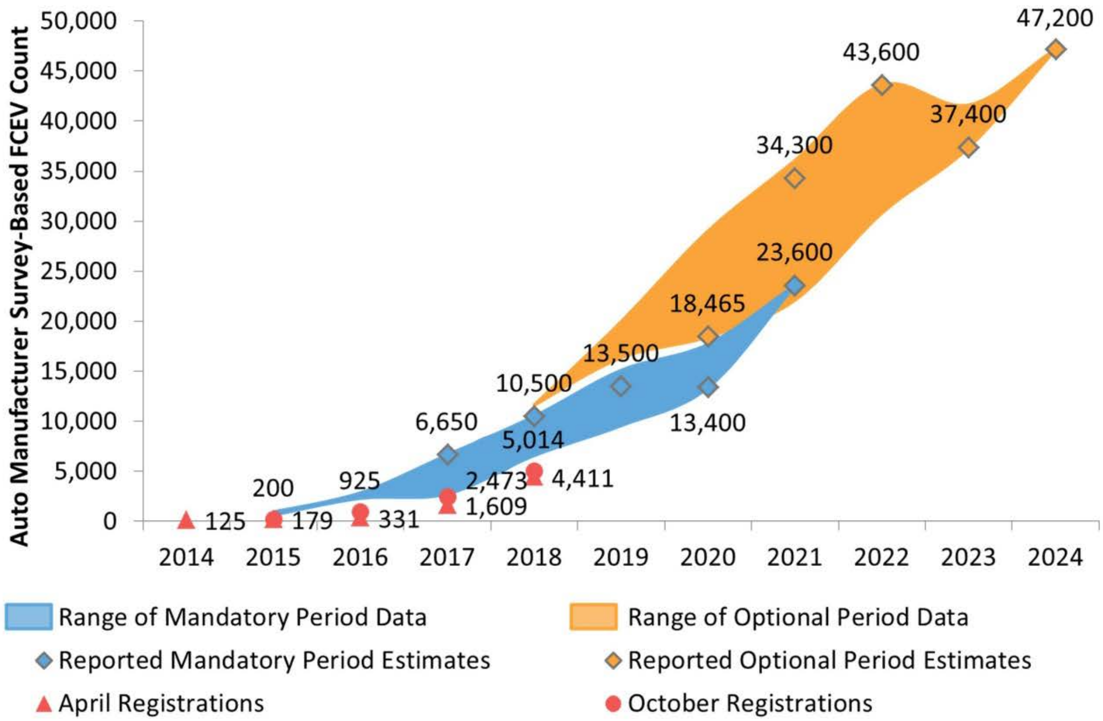
32 The FCEV demand forecast includes a range of values representing different demand cases, from low to high. Each case assumes different economic, demographic, fuel price, and vehicle attribute projections in forecasting transportation energy demand. The most recent Energy Commission forecast anticipates between 25,000 (low demand) and 33,000 (high demand) FCEVs in 2021 and between 56,000 (low demand) and 83,000 (high demand) FCEVs in 2024. A report including the most recent forecasts is under development.

The latest published report that explains the forecasting methodology is: Bahrenian, Aniss, Jesse Gage, Sudhakar Konala, Bob McBride, Mark Palmere, Charles Smith, and Ysbrand van der Werf. 2018. *Revised Transportation Energy Demand Forecast, 2018-2030.* California Energy Commission. Publication Number: CEC-200-2018-003. https://efiling.energy.ca.gov/GetDocument.aspx?tn=223241&DocumentContentId=28845.

33 The industry-reported FCEV numbers are available at https://cafcp.org/by_the_numbers.

34 The 2017 Annual Evaluation is available at https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2017.pdf.

Figure 13: FCEV Count Projections



Source: CARB

Figure 13 presents FCEV projections in the mandatory reporting period (shown in blue, which is the next three model years at the time of survey) and the optional reporting period (shown in orange, which is the following three model years after the mandatory period) for auto manufacturers. In the optional period, some auto manufacturers may not have provided data. The FCEV counts shown in Figure 13, represented by the diamond-shaped icons, are the end-of-period values from the estimates that CARB received from auto manufacturers in each survey year.

In 2018, the end-of-period years were 2021 for the mandatory period and 2024 for the optional period. The blue and orange areas represent the range of survey responses obtained from auto manufacturers for each year that the survey covered the given year. For example, considering 2019, it was the end of the mandatory reporting period in the 2016 survey year. The 2016 estimate for 2019 is shown in the figure as 13,500 FCEVs. CARB's surveys conducted in 2017 and 2018 also collected data on 2019, and the vertical spread of the blue area represents the range of vehicle projections from these other survey years. The increased projections of FCEVs, 23,600 FCEVs by 2021 and 47,200 FCEVs by 2024, sends a positive signal to the hydrogen refueling infrastructure industry that demand for fuel will continue to increase.

CHAPTER 4: Time Required to Permit and Construct Hydrogen Refueling Stations

The continued decrease in station development time observed in 2018 is at least partially due to the emphasis GFO-15-605 placed on station developer readiness. The solicitation required applicants to hold a preapplication meeting with the AHJ and secure the station site through critical milestones. The Hydrogen Draft Solicitation Concepts[35] include the critical milestones in Table 4 and use some as screening tools. Table 5 describes the station development phases.

Table 4: Critical Milestones for Station Development

Critical Milestones	When Required
1: Preapplication meeting for permits with AHJs	At the time of application for varying numbers of stations, depending on the application. For the remaining stations, due on or before the date when addresses for the remaining stations are submitted to the Energy Commission. This is a screening tool in the Hydrogen Draft Solicitation Concepts.
2: Site control	At the time of application for varying numbers of stations, depending on the application. For the remaining stations, due on or before the date when addresses for the remaining stations are submitted to the Energy Commission. This is a screening tool in the Hydrogen Draft Solicitation Concepts.
3: Meeting(s) with a representative of the office of the Fire Marshal in the AHJ	On or before the date specified in the Schedule of Products and Due Dates. This is new in the Hydrogen Draft Solicitation Concepts.
4: Meeting(s) with the utility company	On or before the date specified in the Schedule of Products and Due Dates. This is new in the Hydrogen Draft Solicitation Concepts.
5: Meeting(s) with the hydrogen supply company	On or before the date specified in the Schedule of Products and Due Dates. This is new in the Hydrogen Draft Solicitation Concepts.

Source: California Energy Commission

35 Hydrogen Draft Solicitation Concepts is available at https://www.energy.ca.gov/contracts/transportation.html.

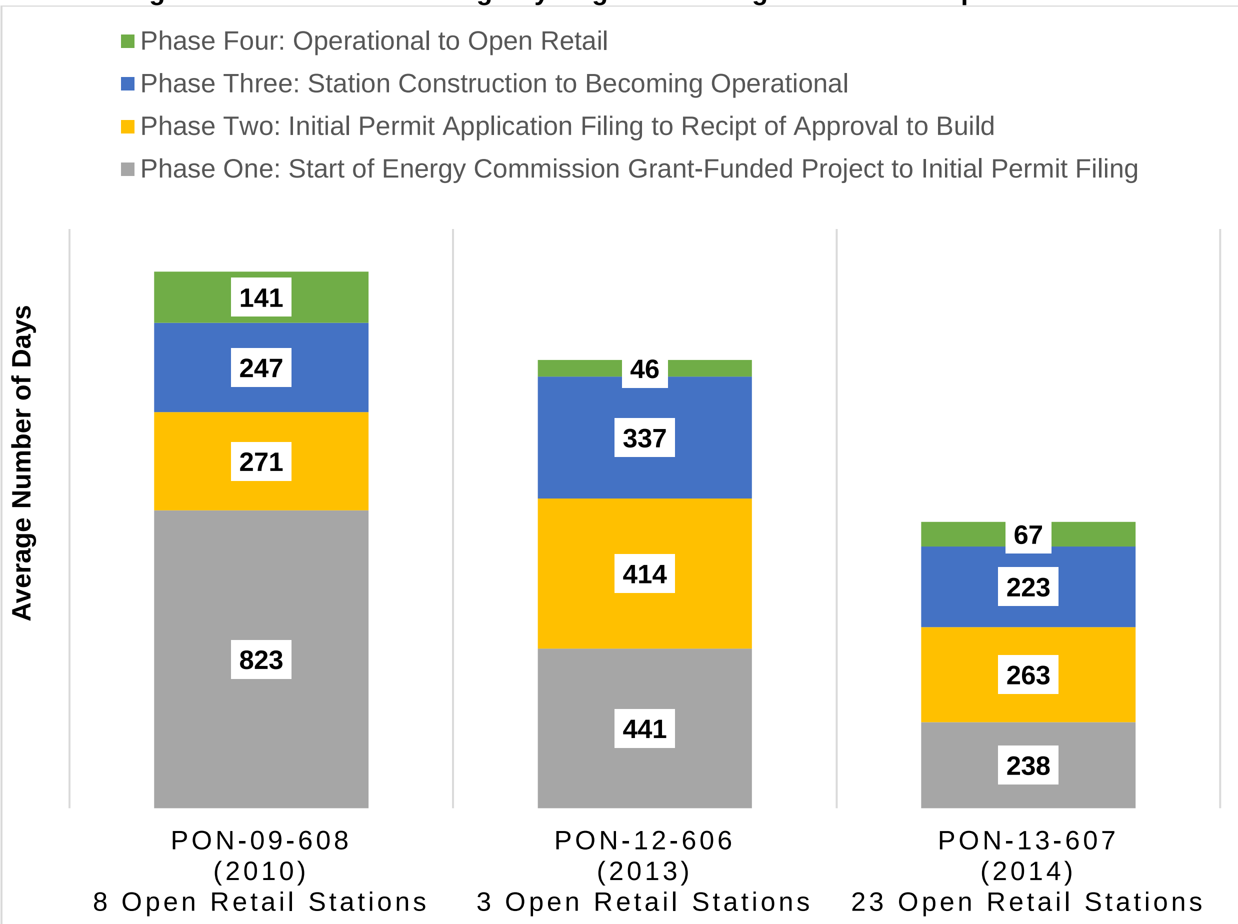
Table 5: Station Development Phases

Phases	Description	Responsible Entity(ies)
Phase One: Start of Energy Commission grant-funded project to initial permit application filing	Begins when the grant-funded project is executed and includes site selection and site control, station planning, participation in prepermitting meetings for confirmation of station design consistency with local zoning and building codes, and filing the initial permit application with the AHJ. Equipment ordering could occur during this phase.	Grant recipient and AHJ
Phase Two: Initial permit application filing to receipt of approval to build	Consists of AHJ review of the application and potential site reengineering/redesign based on AHJ feedback. Minor construction work could start before receiving approval to build depending on risk aversion, given that the approval may take a long time or never come to fruition.	Grant recipient and AHJ
Phase Three: Approval to build to becoming operational	Includes station construction and meeting operational requirements: the station has a hydrogen fuel supply, passes a hydrogen quality test, dispenses at the H70-T40 pressure and temperature per standard (SAE International J2601), successfully fuels one FCEV, and receives an occupancy permit from the AHJ.	Grant recipient and AHJ
Phase Four: Operational to open retail	The station undergoes accuracy testing with the California Department of Food and Agriculture/Division of Measurement Standards (DMS) and protocol testing with auto manufacturers and the Hydrogen Station Equipment Performance (HyStEP) device. Once the station has been confirmed to meet the fueling protocol, the station is categorized as open retail.	Grant recipient, DMS, CARB (HyStEP), and auto manufacturers

Source: California Energy Commission

Figure 14 shows the decrease in average hydrogen refueling station development times by funding opportunity. Figure 14 does not include GFO-15-605 since most stations remain under development. Notably, the Citrus Heights station is the first hydrogen refueling station funded under GFO-15-605 to become open retail. The station was completed 15 months (450 days) after the grant recipient and the Energy Commission signed the agreement that funds the station. The grant recipient proactively worked on Phase One, prior to the grant award, to achieve quick station completion.

Figure 14: Decreased Average Hydrogen Refueling Station Development Times



Source: California Energy Commission

Table 6 shows the average duration of hydrogen refueling station development phases and how many stations have completed each phase per solicitation. For stations funded under GFO-15-605, the average duration for Phase One is almost 85 percent less than the time spent by developers working on PON-13-607 stations. Some developers acted before the grant agreement execution, and this resulted in a significant decrease in the time spent in Phase One. Thus far, 4 out of 20 stations funded under GFO-15-605 completed Phase Two with the same duration as the stations funded under PON-13-607 for Phase Two.

Table 6: Average Duration of Hydrogen Refueling Station Development Phases

Solicitation/Contract	Phase One	Phase Two	Phase Three	Phase Four
GFO-15-605[36] **(2015)**	**36 days**	**264 days**	*NA*	*NA*
	13 of 20 stations	*4 of 20 stations*	*0 of 20 stations*	*0 of 20 stations*
PON-13-607[37] **(2014)**	**238 days**	**263 days**	**223 days**	**67 days**[38]
	25 of 25 stations	*25 of 25 stations*	*23 of 25 stations*	*23 of 25 stations*
PON-12-606 (2013)	**441 days**	**414 days**	**337 days**	**46 days**
	4 of 4 stations	*4 of 4 stations*	*3 of 4 stations*	*3 of 4 stations*
PON-09-608 (2010)	**823 days**[39]	**271 days**	**247 days**	**141 days**
	10 of 10 stations	*8 of 10 stations*	*8 of 10 stations*	*8 of 10 stations*

Source: California Energy Commission

The same factors described in the 2016 and 2017 Joint Reports affect station development time, such as the variable in executing a lease and site improvements required of the station owner that the station developer does not anticipate. Some station developers building stations funded under GFO-15-605 met critical milestone requirements and completed the early phases of development by:

- Requesting a preliminary planning assessment from each AHJ to receive feedback on next steps and any potential concerns before submitting applications to the solicitation.
- Commencing the permitting process immediately after the Energy Commission released the NOPA, before the Energy Commission Business Meeting approval.
- Securing leases, in many cases before submitting applications to the solicitation.
- Partnering with a gas station retailer to secure multiple station locations at once, rather than negotiating with independent owners for site control for each location.
- Negotiating early with equipment suppliers to be ready to place a purchase order immediately after grant agreement execution.

The time spent permitting a hydrogen refueling station may be influenced by the requirements of the California Environmental Quality Act (CEQA). The Energy Commission conducts an environmental review for all the ARFVTP-funded hydrogen refueling stations, either as lead or responsible agency. In most previous cases, the Energy Commission has determined that the hydrogen refueling stations are categorically exempt from CEQA and has filed a notice of

36 The average duration for Phase Three and Phase Four for GFO-15-605 is not reported due to an inadequate sample size.

37 One station is not included in the average duration for all phases for PON-13-607 because it was relocated to a site with an existing nonretail station, and the associated site upgrade was not representative of a typical station development.

38 One station is not included in the Phase Four average for PON-13-607 due to it being an outlier that experienced unforeseeable and unusual circumstances.

39 Two stations that experienced extenuating circumstances are not included in the Phase One average for PON-09-608.

exemption (NOE) with the Governor's Office of Planning and Research State Clearinghouse.[40] Notably, the Energy Commission findings are not typically binding on the cities in which stations are proposed, and in some cases an AHJ required a station project to go through an initial study. This occurred in 3 percent of station projects thus far.

The Energy Commission used the following categorical exemptions, often citing more than one, in CEQA determinations for hydrogen refueling stations.[41] In the list below, the percentage of station projects for which the Energy Commission used the particular citation follows the code section name.

- 14 C.C.R. § 15061(b)(3), no possibility of impact ("common sense" exemption): 2 percent
- 14 C.C.R. § 15301 Existing Facilities: 91 percent
- 14 C.C.R. § 15302 Transfer of Community Property to Third Person: 2 percent
- 14 C.C.R. § 15303 New Construction or Conversion of Small Structures: 88 percent
- 14 C.C.R. § 15304 Minor Alterations to Land: 56 percent

Station Testing in Phase Four

Phase Four involves confirming the performance of the hydrogen refueling station. California stations must be tested and certified that they are delivering hydrogen free from contaminants, and that the mass of hydrogen is dispensed accurately. Additional testing is performed that helps ensure the station follows the standard filling procedure that provides the customer a safe and full vehicle fill every time.

California uses the Hydrogen Station Equipment Performance (HyStEP) device to test station performance. HyStEP tests stations according to the American National Standards Institute/CSA Group Hydrogen Gas Vehicle and Fueling Installations 4.3, Test Methods for Hydrogen Fueling Parameter Evaluation (CSA HGV 4.3). CSA HGV 4.3 is a test method that validates conformance with SAE International J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles standard.[42]

The Energy Commission agreements require that hydrogen refueling stations conform to SAE International J2601. SAE International J2601 establishes the protocol and process limits for hydrogen fueling of light-duty vehicles. These include limits for the fuel temperature, the maximum fuel flow rate, the rate of pressure increase, and the ending pressure.

The stations undergo performance testing by auto manufacturers and the station developer to become open retail. The HyStEP device streamlines and accelerates the process. CARB and

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40 Information on the OPR State Clearinghouse is available at http://opr.ca.gov/clearinghouse/ceqa/.

41 CEQA Guidelines information is available at http://opr.ca.gov/ceqa/.

42 Stations in California are also required to comply with the California Fire Code, which adopts the NFPA 2 Hydrogen Technologies Code to provide fundamental safeguards for the generation, installation, storage, piping, use, and handling of hydrogen in compressed gas (GH2) form or cryogenic liquid (LH2) form. NFPA 2 is a key component of the approval process that hydrogen stations go through with local authorities.

CDFA/DMS staff test and report the results to the auto manufacturers. Auto manufacturers (at least three) then confirm the station as open retail.

CDFA/DMS conducts "type evaluations" for hydrogen dispensers through the California Type Evaluation Program (CTEP).[43] DMS plays a major role in station commissioning by conducting metrology compliance tests for station dispensers under California regulations. These tests ensure that commercial sale of hydrogen is measured accurately.

California Code of Regulations Title 4, Division 9, Chapter 6, Article 8, Section 4181 adopts SAE International J2719 for hydrogen fuel used in internal combustion engines and fuel cells. In addition to metrology testing by CDFA/DMS, the purity of dispensed hydrogen is evaluated and reported by commercial testers. Some Energy Commission grant agreements require quality checks at least every three months, while the Hydrogen Draft Solicitation Concepts propose the quality check every six months. Furthermore, most grant agreements require hydrogen quality checks any time station plumbing is potentially exposed to contamination due to a station retrofit or other station adjustment.

As discussed in the 2017 Joint Report, as more stations are built, the need for more station testing, optimization, and tuning grows, at times requiring HyStEP testing at multiple stations simultaneously. Sometimes, the stations will be located in places far from each other, which strains the HyStEP team for practical reasons. Optimally, a new screening device with limited testing and tuning capabilities could help demonstrate that a station is ready for full-scale CSA HGV 4.3 tests. Such a device also could be small enough to fit in the back of a truck for easy transport between stations. This device is not presently planned or funded.

Since the HyStEP device is on loan from U.S. DOE to the State of California, the long-term availability of the device is uncertain. Therefore, CARB works to assess the interest of Nationally Recognized Testing Laboratories (NRTLs) to augment or supplant HyStEP, or both. Because some stations required more than one HyStEP visit before tests were passed, CARB continues to explore the idea of offering HyStEP to station developers for preliminary evaluations on a fee-for-service basis, enabling developers to troubleshoot issues before official testing.

Moving forward, CARB has begun looking into the need for a regulation requiring public light-duty hydrogen refueling stations to comply with SAE International J2601. CARB held a public workshop to solicit public input on November 29, 2018. In addition to requiring SAE International J2601 compliance, important considerations are the involvement of third-party entities in station verification and the integration of factory certification into the verification process.

43 Information on CTEP is available at https://www.cdfa.ca.gov/dms/programs/ctep/ctep.html.

CHAPTER 5: Amount and Timing of the Growth of the Hydrogen Refueling Network

Continuing the analyses begun in the 2017 Joint Report, the Energy Commission evaluates how the latest vehicle projections from CARB align with station development in four regions. Table 7 presents conservative estimates of the projected regional need for fuel. The table, which does not include connector and destination stations, compares 80 percent of the 65-station network capacity to the estimated amount of fuel needed per day to support the anticipated population of FCEVs in 2024 in each region. Nearly 17,000 kilograms per day of additional capacity is needed to meet the projected demand.

Table 7: Regional Projection for the Need for Fuel

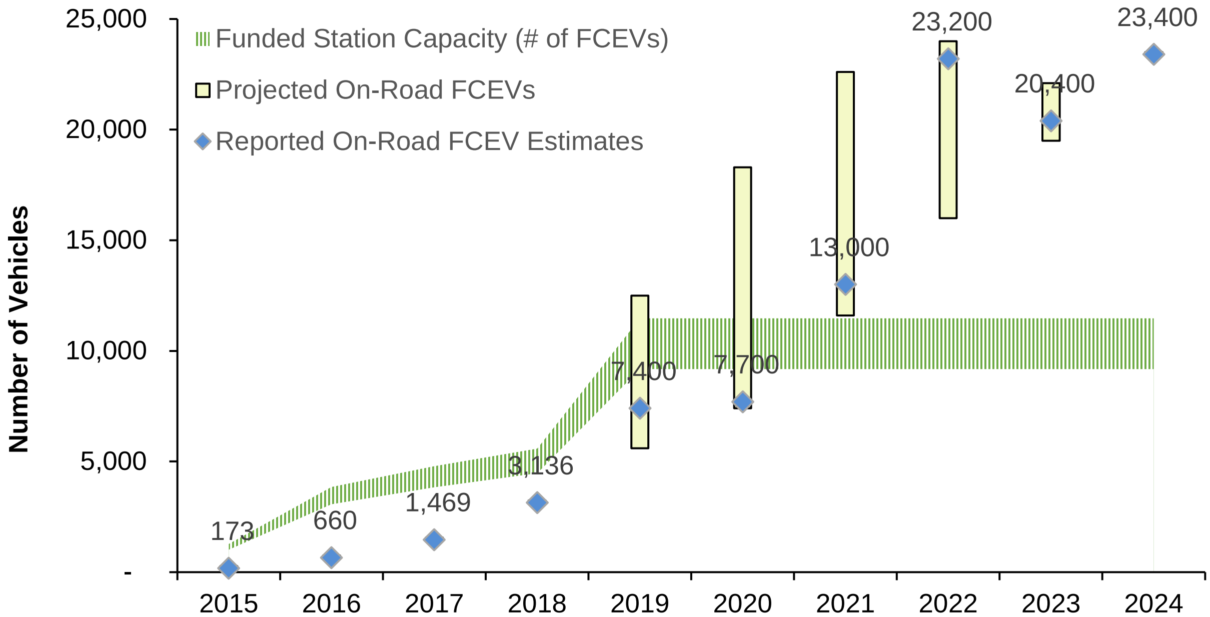
Region	80% of Capacity (kg/day)	Projected FCEVs by 2024	Nameplate Capacity Needed by 2024 (kg/day)	Additional Needed Capacity for Projected Demand by 2024 (kg/day)
Greater Los Angeles Area	6,400	23,400	16,400	10,000
San Francisco Bay Area	5,100	13,100	9,200	4,100
San Diego Area	500	2,900	2,000	1,500
Sacramento Area	900	3,200	2,200	1,300
Total	12,900	42,600	29,800	16,900

Source: California Energy Commission

The following analyses compare CARB's estimated FCEV rollout to the estimated station deployment (based solely on the funded station network) in each region. Figure 15 shows the need for fuel with a possible shortfall of hydrogen availability as early as 2019 and almost certainly by 2021 in the Greater Los Angeles Area. The yellow bars in the figure show the range of CARB-estimated FCEVs from multiple annual surveys of auto manufacturers. The developers' timelines are used to estimate the year of station completion for stations yet to become open retail.

The analyses use 0.7 kilogram per day of hydrogen consumed per FCEV to convert station capacity into the estimated number of FCEVs supported. The green lines in the figure indicate the estimated number of FCEVs that could be supported by a region's stations. The width of the green line represents the difference between using 100 percent of the station nameplate capacity to determine the number of FCEVs supported (the upper bound) and using 80 percent (the lower bound). These green lines level off in 2019 because all the currently funded stations are expected to become open retail in the 2019–2020 time frame. These lines will increase as additional stations are funded and built.

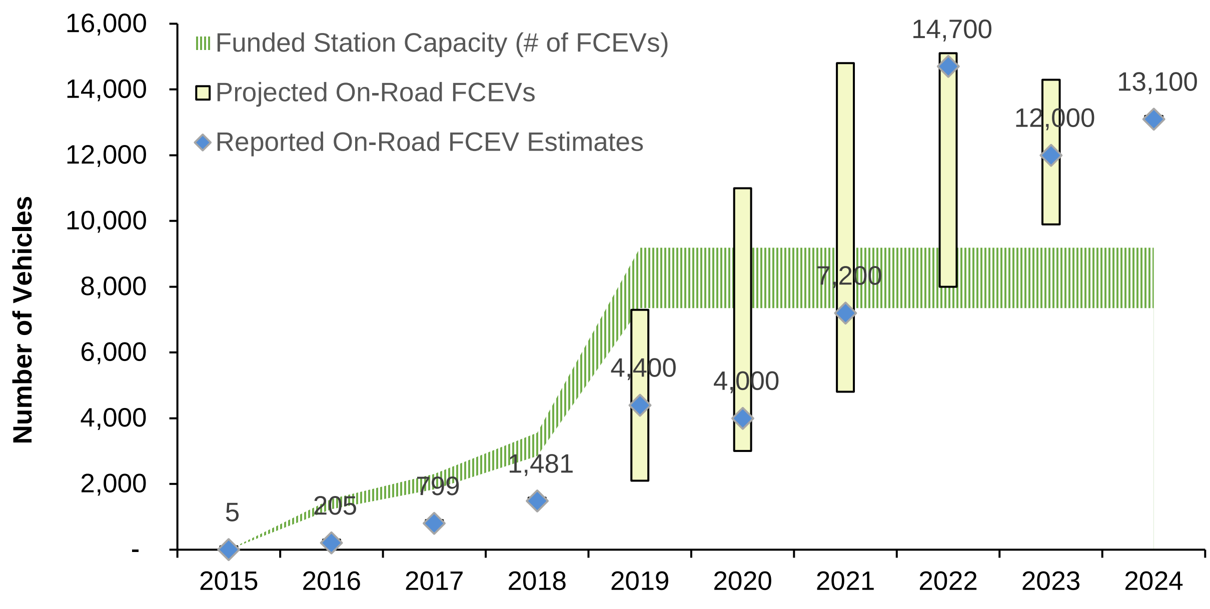
Figure 15: Greater Los Angeles Area Station Network Capacity and Number of Vehicles



Source: California Energy Commission

Figure 16 shows that the capacity of the funded network in the San Francisco Bay Area is likely to satisfy FCEV fueling needs until sometime post-2020.

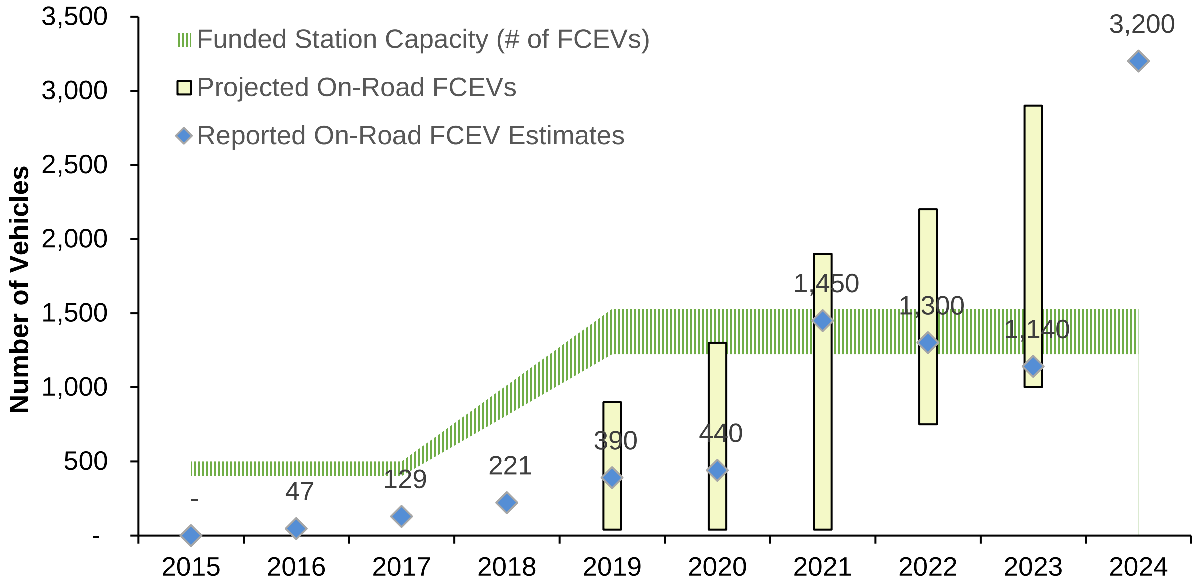
Figure 16: San Francisco Bay Area Station Network Capacity and Number of Vehicles



Source: California Energy Commission

As reported in the 2017 analysis, the Sacramento region continues to present the healthiest picture of capacity relative to vehicles, with current network capacity likely to satisfy demand until sometime around 2022. The Sacramento region has the most time before the demand exceeds the supply of fuel. However, the most recent CARB projections indicate a strong uptick in FCEV population that the station network will need to satisfy by 2024. Given that auto manufacturers may be anticipating a strengthening of the Sacramento area market, station planning for this region is important to do now, similar to other major metropolitan areas of the state.

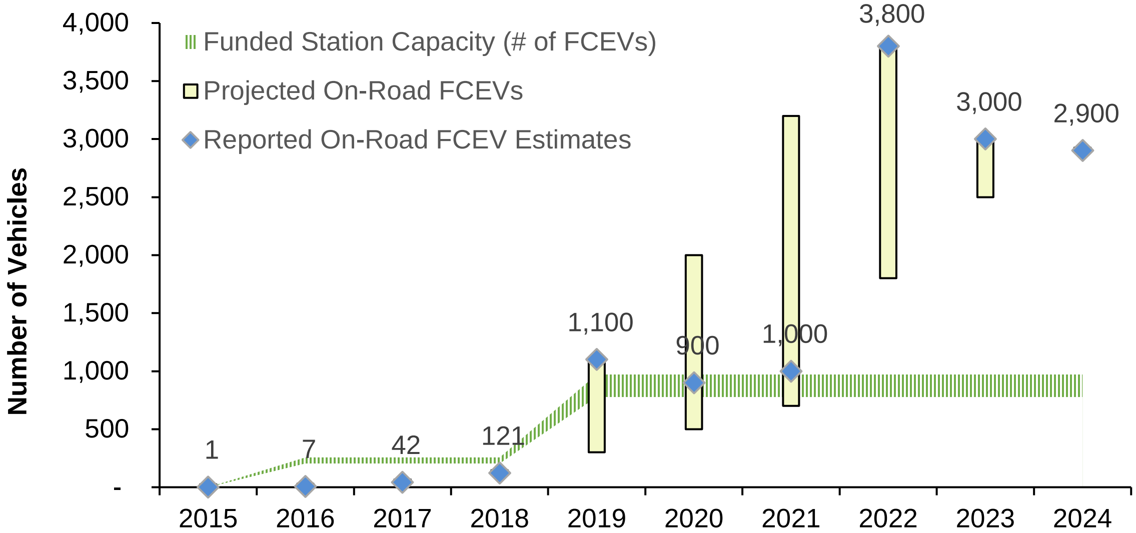
Figure 17: Sacramento Area Station Network Capacity and Number of Vehicles



Source: California Energy Commission staff

Figure 18 demonstrates the San Diego area's potential to operate at capacity between 2019 and 2021, with about three times the current capacity needed by 2022. The San Diego FCEV projections have a particularly large range of values, from fewer than 1,000 to more than 3,800 FCEVs, between 2021 and 2022. Given the most recent projection of 2,900 FCEVs in 2024, the lower ends of the projected ranges appear to represent the more likely growth scenario for FCEV deployment.

Figure 18: San Diego Area Station Network Capacity and Number of Vehicles



Source: California Energy Commission

CHAPTER 6: Remaining Cost and Time Required to Establish a Network of 100 Publicly Available Hydrogen Refueling Stations

The current hydrogen refueling network consists 64 ARFVTP-funded and 1 fully privately funded station upgrade. The remaining estimated ARFVTP cost to establish a network of 100 publicly available hydrogen refueling stations is $110 million in addition to private funds. Thus far, reported private funds invested in the 64 ARFVTP-funded stations are between 30 and 70 percent of the total cost, which is significantly more than what was required in solicitations. The remaining time required to establish the network of 100 stations is nearly six years, or until 2024.

The 2017 Joint Report assumed funding 10 stations annually with a fueling capacity of 300 kilograms per day, whereas the 2018 Joint Report assumes as many as 15 stations could be opened annually. In contrast and based on the industry feedback received during public workshops, the Energy Commission staff developed the Hydrogen Draft Solicitation Concepts that include an idea of awarding the remaining funding through the end of AB 8, subject to future funding appropriations and future ARFVTP Investment Plan allocations.[44] This amount is $110 million. By enabling developers to achieve economies of scale, reducing cost per kilogram and cost per station, the strategy should result in California exceeding the 100-station goal, with many urban area hydrogen refueling stations having at least 500 kilograms per day of capacity, with the remaining ARFVTP funding.

With the Hydrogen Draft Solicitation Concepts, the Energy Commission staff estimates about 15 stations will become open retail annually, with some reaching completion as early as 2020, and with steady growth from 2022 on. With such a growth pattern, staff estimates 110 open retail stations in 2024. The supply of fuel from the 110 projected open retail stations roughly matches the projected need for fuel by 47,200 FCEVs by 2024.

Low Carbon Fuel Standard (LCFS)

This year, CARB approved amendments to the Low Carbon Fuel Standard (LCFS) regulation.[45] The amended regulation includes a new credit-generating system for hydrogen refueling infrastructure (HRI). HRI credits offer an additional incentive to station operators to build appropriate fueling capacity to support a larger FCEV market and to reduce both the emissions intensity and retail price of the hydrogen dispensed at stations by enabling operators to obtain

44 Modifications to the 2018-2019 ARFVTP Investment Plan Update was approved on October 3, 2018, https://www.energy.ca.gov/business_meetings/2018_packets/2018-10-03/Item_01d.pdf.

45 The 2018 LCFS regulation update information is available at https://www.arb.ca.gov/regact/2018/lcfs18/lcfs18.htm.

credits for the capacity of their stations, not just the portion of capacity that is dispensed. The LCFS creates an incentive to maximize station availability to increase potential LCFS credit revenue. This may help the industry develop more stations more quickly, with less Energy Commission grant funding. With organizations like the Hydrogen Council committed to decarbonizing hydrogen fuel,[46] and with investment from the Energy Commission and private industry in renewable hydrogen production, the carbon intensity (CI) of hydrogen likely will decrease over time. A decrease in CI would increase the potential for LCFS credit generation from hydrogen.

The updated LCFS regulation, intended to be effective January 1, 2019 (pending approval by the Office of Administrative Law), defines eligibility and application requirements for hydrogen station owners to earn HRI credits. HRI credits are generated based on the unused refueling capacity of a given station and are generated in parallel with LCFS credits based on actual quantity of fuel dispensed. Once the regulation becomes effective, hydrogen station owners will be able to apply to CARB, through the established LCFS Reporting Tool and Credit Bank & Transfer System (LRT-CBTS), to be considered for an HRI pathway. Station owners may apply for stations currently in operation and for future stations, provided that such stations become operational within 24 months of the application approval date. Applications will not be accepted after December 31, 2025.

Application Process Overview

Applicants must provide information explicitly defined by CARB in the regulation, including company contact information, station location, permitted hours of operation, station nameplate capacity per the Hydrogen Station Capacity Evaluation (HySCapE) model, number of dispensers, expected CI and source(s) of hydrogen, and justification of station location. The application package must include a signed attestation as to the veracity of the information from an authorized company representative.

CARB will review the application, and the station owner will receive notice from the CARB Executive Officer if the application is complete or incomplete. If incomplete, CARB will ask the station owner to provide the missing information, and the station owner has 180 days from initial CARB receipt of the application in which to complete the application. If the station owner does not meet that deadline, the application will be denied.

The Executive Officer will evaluate the proposed station location and capacity and whether approval of the new application will cause HRI credits to exceed the programmatic limit established in the regulation. Estimated potential HRI credits may not exceed 2.5 percent of total LCFS program deficits generated in the previous quarter. If approval of the new application would result in the program exceeding this limit, the Executive Officer will stop approving HRI pathways and will not accept additional applications until estimated potential

46 Information about the Hydrogen Council's goal for to decarbonizing hydrogen is available at http://hydrogencouncil.com/our-2030-goal/.

HRI credits are less than 2.5 percent of the prior quarter's deficits. HRI applications will be evaluated for approval on a first-come, first-served basis.

Once an application is approved, the 15-year HRI crediting window begins in the following quarter. To begin generating HRI credits, the station must be open to the public, able to accept major credit and debit cards through a public point-of-sale terminal, connected to the Station Operational Status System (SOSS), approved through the CTEP process as described previously and meet the appropriate SAE International fueling protocol. These match requirements of GFO-15-605, the Energy Commission's most recent hydrogen station solicitation. The station must be approved by at least three automotive original equipment manufacturers. The station owner must also maintain a companywide weighted average of at least 40 percent renewable hydrogen (renewable content based on feedstock alone for steam methane reforming and based on electricity to the electrolyzer for electrolysis) and a hydrogen CI of 150 grams of CO_2 equivalent per megajoule[47] (gCO_2e/MJ) or fewer. It must also provide specified data to CARB related to station costs and revenues for CARB to track the performance of the program and make adjustments in future regulatory amendments, as needed.

The formula for generating HRI credits is defined in the LCFS regulation, and credits may be generated quarterly. Predictions of HRI credit revenue for a given station vary based on many factors, including the CI of dispensed fuel, LCFS credit prices, and station availability ("uptime"). Once credits are received, it is up to the station owner to decide when it wants to sell the credits. For credit exchanges, no differentiation is made between HRI credits and other LCFS credits (although HRI credit generation is tracked separately in analyses of overall program benefits).

If a hydrogen refueling station does not become operational within 24 months of application approval, the station owner will need to reapply to the program and, if approved, will be eligible only for a 10-year crediting period.[48] In the first and second quarters of 2019, CARB will approve applications for HRI crediting up to the point in which estimated total HRI credits reach 2.5 percent of deficits. In subsequent quarters, prospective applicants can project the likelihood of additional applications being considered for approval in a given quarter based on quarterly credit and deficit reports published on the LCFS website and based on the LCFS, which increases in stringency every year, thereby allowing for additional applications to be considered. Therefore, applicants to the next GFO will know the amount of credits their proposed stations are likely to receive.

Under ARFVTP Contract 600-15-001, Technical Support for the ARFVTP, NREL developed the HySCapE tool[49] that calculates hydrogen station dispensing capacity. HySCapE will provide a consistent way to evaluate station dispensing capacity using inputs from the station developers that include station storage volumes, station configurations and pressures, compressor

47 A joule is a unit of energy. It's equal to 1/3600th of a watt-hour. A megajoule is equal to 1 million joules.

48 The 2018 LCFS regulation update information is available at https://www.arb.ca.gov/regact/2018/lcfs18/lcfs18.htm.

49 HySCapE may be downloaded at https://www.arb.ca.gov/fuels/lcfs/ca-greet/2018-0813_hyscape1.zip.

performance, vehicle demand, and production and delivery methods for the hydrogen refueling stations.

Both the LCFS and the Energy Commission Hydrogen Draft Solicitation Concepts include HySCapE as a model to use when articulating planned station capacity. Potentially, the tool will be useful for evaluating actual station capacity, once a station is built and commissioned.

Sample Analysis of Potential LCFS Revenue With HRI Credits

In the following figures, Energy Commission staff estimates the potential LCFS revenue for a small-capacity station (180 kilograms per day) and for a large-capacity station (1,200 kilograms per day, the maximum station capacity allowed for generating HRI credits). The potential LCFS revenue includes that from HRI credits (labeled in the figures as "infrastructure") and hydrogen dispensing (labeled "dispensing").

This sample analysis is included in the 2018 Joint Report to provide a perspective of the possible revenue impact of the LCFS update on today's hydrogen refueling stations, which can apply for HRI credits and earn revenue from dispensing. The Energy Commission and CARB will closely monitor hydrogen station owner participation in the LCFS to evaluate how HRI credits are influencing the speed and volume of hydrogen station development. Staff used this set of assumptions to produce Figures 19 and 20:

- Period: HRI credits may be earned for up to 15 years, here assumed as 2019 to 2033. If a station is not operational at the time of HRI project approval, then the crediting period will be reduced by the length of time it takes for the station to become operational from the time of application approval. Details about how station owners must verify their station is in operation are found in the updated LCFS regulation.
- Hydrogen CI: the 180-kilogram-per-day station is assumed to use gaseous compressed hydrogen produced at a central steam methane reformation (SMR) facility with a nonrenewable CI of 117.67 gCO_2e/MJ and a renewable CI of 99.48 gCO_2e/MJ. Assuming 40 percent renewable hydrogen, the combined CI is 110.39 gCO_2e/MJ.

  The 1,200-kilogram-per-day station is assumed to use liquid hydrogen produced at a central SMR, with a nonrenewable CI of 150.94 gCO_2e/MJ and a renewable CI of 129.09 gCO_2e/MJ. Assuming 40 percent renewable hydrogen, the combined CI is 142.2 gCO_2e/MJ. These values are from the LCFS Lookup Table in the 2018 updated regulation.
- Station Availability (Station Uptime): 95 percent. The HRI credit formula includes station availability, which is factored into station capacity for the hydrogen that is not dispensed to determine the number of HRI credits earned. The HRI credits added to the credits for dispensed hydrogen (see below) yields the total station credit potential.
- Percentage Utilization: assumed to begin in 2019 at 25 percent and to increase by 5 percent annually until reaching 95 percent in 2033. With the 95 percent uptime assumption, in 2033, zero capacity credits are earned, and credits could only be earned from dispensed fuel. The station use determines the amount of dispensed hydrogen, which is needed to calculate credits.

- LCFS Credit Price: $100 per credit. NOTE: This credit price is only an example. Current market prices should be sought.
- Gasoline CI Standard: The CIs used are per the 2018 updated LCFS regulation for the CI benchmarks for gasoline and fuels used as a substitute for gasoline, beginning in 2019 with a CI of 93.23 gCO_2e/MJ and continuing to 2030 and subsequent years with a CI of 79.55 gCO_2e/MJ. Because the benchmark CI decreases and then remains constant after 2030, and the hydrogen CI is held constant throughout, the combined LCFS revenue in the figures decreases slightly each year until 2030 and then remains constant.
- Energy Economy Ratio (EER): 2.5, per the LCFS regulation. The EER means the dimensionless value that represents the efficiency of a fuel as used in a powertrain as compared to a reference fuel used in the same powertrain.[50] The EER used here compares the miles per gasoline gallon equivalent of hydrogen to the gasoline baseline.
- Energy Density: 120 MJ/kg, per the LCFS regulation. The energy density, or the amount of energy stored in the hydrogen, is typically between 120 and 142 MJ/kg.[51]

These assumptions are used in the following LCFS formulas to calculate HRI (infrastructure) and dispensing credits. These formulas are for calculating credits over one quarter, and the figures aggregate the quarterly values to show annual totals.

HRI Credits

HRI Credits = (Gasoline CI Standard **X** EER – Hydrogen CI) **X** Energy Density **X** (Station Capacity **X** Number of Days in Quarter **X** Station Availability – Dispensed Hydrogen) **X** 10^{-6}

Dispensing Credits

Dispensing Credits = (Gasoline CI Standard **X** EER – Hydrogen CI) **X** Energy Density **X** Dispensed Hydrogen **X** 10^{-6}

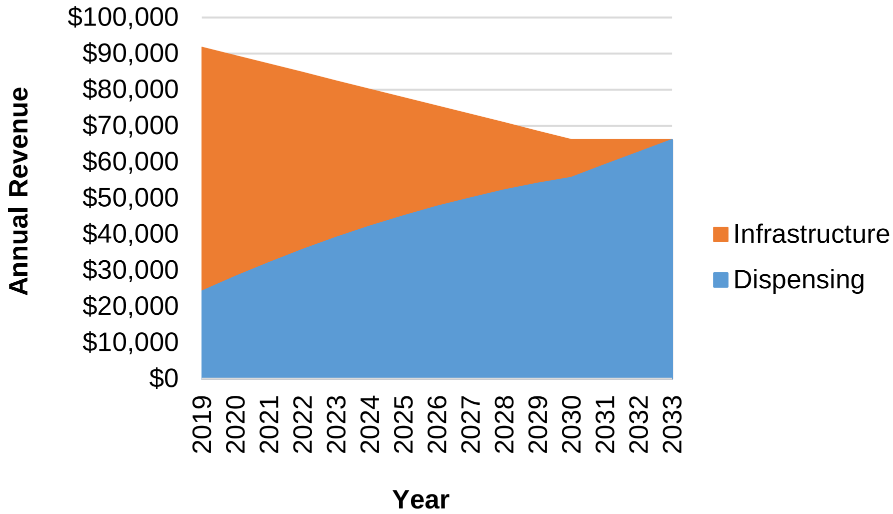
In comparing the LCFS value over a lengthy 15-year time horizon, another aspect to consider is the discount rate to apply to future credit revenue to obtain the potential present value of credits over the life of the program. The analysis presented here does not apply a discount rate and, therefore, treats a dollar earned in the future as equivalent to a dollar earned today.

In the following figures, the area shaded in orange is the revenue from HRI credits, and the area shaded in blue is the revenue from LCFS credits earned by dispensing hydrogen. The total shaded area represents total revenue. Because station utilization is assumed to grow over time, meaning the station dispenses more fuel each year, the proportion of revenue from dispensing increases over time while the revenue from HRI credits decreases.

50 Low Carbon Fuel Standard Section 95481. Definitions.

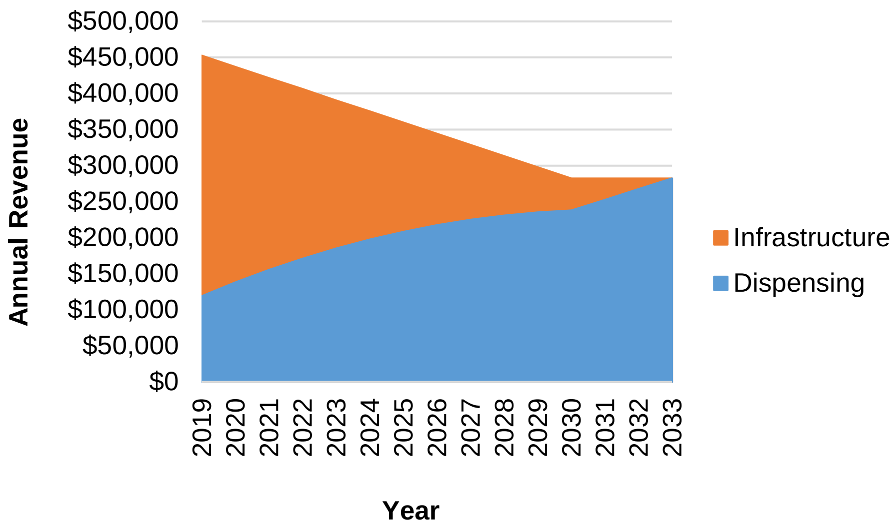
51 https://hypertextbook.com/facts/2005/MichelleFung.shtml.

Figure 19: Estimated LCFS Revenue for a 180 kg/day Station With Initial Assumptions



Source: California Energy Commission

Figure 20: Estimated LCFS Revenue for a 1,200 kg/day Station With Initial Assumptions



Source: California Energy Commission

As seen in Figure 19, the potential annual revenue for the 180-kilogram-per-day station ranges from about $70,000 to $90,000. Overall potential LCFS revenue for the 180-kilogram-per-day station over the 15-year period is estimated at $1.14 million, with nearly $690,000 coming from dispensing credits and $450,000 from HRI credits. At the high end, with the largest possible station of 1,200 kilograms per day (shown in Figure 20), annual revenue ranges from nearly $300,000 to $450,000, and nearly $5.25 million could be generated over 15 years. Of this total, nearly $3.12 million is from dispensing credits and $2.13 million from HRI credits.

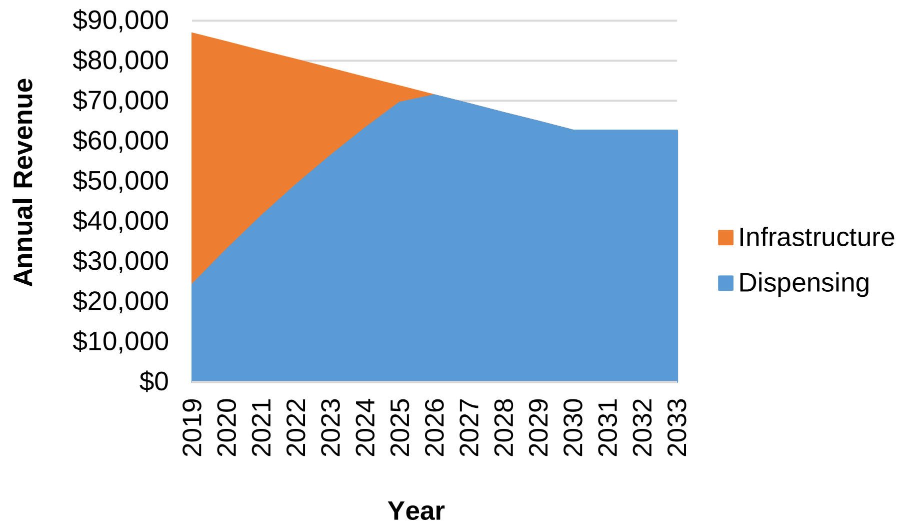
This analysis presents a conservative picture of station utilization. Knowing that a few existing stations are already reaching operational capacity after only a few years of operation, in some cases, where station developers expect high demand, it could be more realistic to presume a faster ramping up of station utilization. On the other hand, it is also possible that utilization will peak at a lower percentage than 95 percent, possibly due to lower uptime.

To see how adjusting the utilization rate and uptime changed the revenue picture, Energy Commission staff evaluated a second set of assumptions. All other assumptions are the same, and two are adjusted:

- Station Availability (Uptime): 90 percent.
- Percent Utilization: assumed to begin in 2019 at 25 percent and increasing by 10 percent per year until reaching 90 percent in 2026. With the 90 percent uptime assumption, this means in 2026 and thereafter, zero capacity credits are earned.

Figures 21 and 22 show the estimated revenue patterns with the adjusted assumptions.

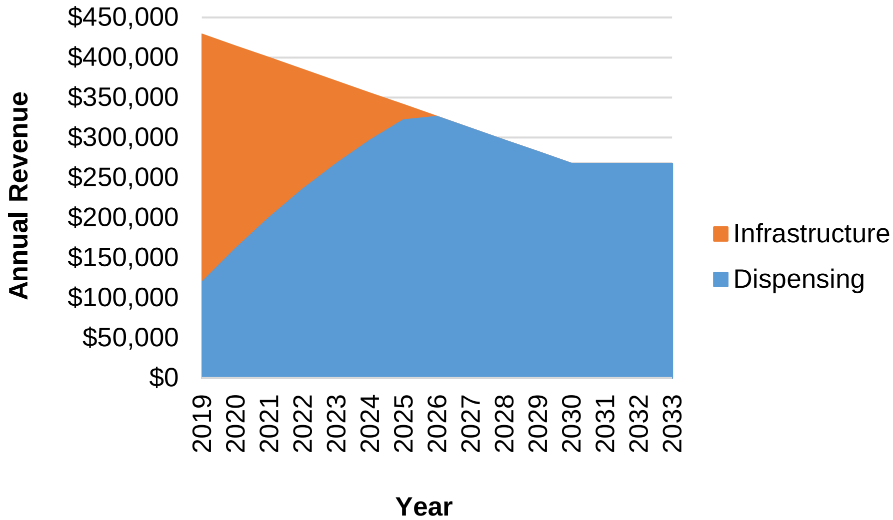
Figure 21: Estimated LCFS Revenue for a 180 kg/day Station With Adjusted Assumptions



Source: California Energy Commission

For the 180 kilogram-per-day station, with these adjusted assumptions, the 15-year total estimated revenue is $1.08 million, with $860,000 coming from dispensing and $220,000 from HRI credits.

Figure 22: Estimated LCFS Revenue for a 1,200 kg/day Station With Adjusted Assumptions



Source: California Energy Commission

The 1,200–kilogram-per-day station earns an estimated $4.98 million over 15 years, with $3.89 million from dispensing and $1.09 million from HRI credits. Compared to the first set of figures, this second set shows how higher station utilization results in fewer HRI credits and more dispensing credits being generated, and how lower station uptime reduces overall revenue. This analysis demonstrates how the LCFS program creates an incentive for station owners to maximize station availability to increase potential LCFS credit revenue.

While not explored in this analysis, increasing the amount of renewable hydrogen used at a station also has the potential to increase revenue. Potential revenue increases as the CI of hydrogen relative to the gasoline baseline CI decreases. In addition, the price of an LCFS credit can fluctuate. Recently, the credit price has been near $180, and if credit prices remain high, this also increases potential revenue for credit-generating entities like hydrogen refueling stations. This analysis uses $100 as the credit price to produce a relatively conservative picture of revenue, not knowing how credit prices could change over the next 15 years.

From the examples presented above, it is clear that HRI credits have the potential to help hydrogen station owners cover costs during years when station utilization is low. Given that HRI credits also offer the potential of a more consistent and predictable revenue stream than with dispensing credits alone, this increased certainty of return on investment has the potential to accelerate the rate of station development and to reduce the amount of ARFVTP funding needed per station by attracting more private investment. Future joint reports will evaluate how the cost and time of station development is changing relative to station owners' participation in the LCFS program. CARB and the Energy Commission also are committed to working together to ensure that the combination of the LCFS program and ARFVTP grant funding are not overcompensating hydrogen station owners. The two state agencies will continue to collaborate in administering their respective programs to find the right balance of incentives that will lead to mature, self-sustaining markets for zero-emission transportation solutions.

Mobile Source Air Pollution Reduction Review Committee (MSRC) Update

On April 6, 2018, the MSRC released a $3 million first-come, first-served solicitation to fund upgrades for stations in the SCAQMD region that have already undergone vetting by the Energy Commission or SCAQMD. The MSRC Technical Advisory Committee recommended approval of a $1 million award to UC Irvine, which was approved by the SCAQMD Governing Board on October 5, 2018. The SCAQMD Governing Board also approved an additional $400,000 award from SCAQMD on November 2, 2018.

The Energy Commission approved another $400,000 toward the project at the November 7, 2018, Business Meeting that was the final funding piece required for the project to move forward. The UC Irvine hydrogen station has been open to the public since 2015 as a result of ARFVTP funding. The proposed upgrade would increase the daily capacity of the station from 180 kilograms per day gaseous hydrogen to 800 kilograms per day liquid hydrogen and add a second hydrogen dispenser to the station, creating a total of four refueling positions.

CHAPTER 7: Self-Sufficiency Evaluation of Hydrogen Refueling Stations

As introduced in the 2016 Joint Report and again in 2017, CARB and the Energy Commission have been working to assess industry-conveyed markers of a self-sufficient hydrogen fueling market and the potential network development trajectory in future years. The goals of the study include projecting the potential state investment and associated investment timeline such that the emerging hydrogen fueling market can be appropriately supported until the industry can be self-reliant for further development.

Over the past two years, the agencies have contacted several stakeholder companies that act in various roles toward the goal of hydrogen refueling station network development. Many of the contacted companies are themselves operators or developers (or both) of at least one hydrogen refueling station in California and can therefore provide firsthand perspective on the current status of network development and the projected needs for enabling a self-sufficient market. Overall, the agencies have to date had more than an 80 percent response rate for the groups of stakeholders that have been contacted for the first set of analyses. One set of stakeholders has not yet received enough responses for that group to be reported. The results below present an industrywide summary of survey responses across all stakeholder responses received to date. Not all companies responded to all questions, and in some cases, some companies may have provided multiple responses to a single question. Responses for groups of companies with similar business operations and roles (industrial gas companies, station equipment providers, and independent operators) in California's hydrogen refueling network are additionally provided in Appendix C.

The material presented in this chapter and Appendix C provides only a reporting of direct responses received to date through the survey. Industry responses to the survey were provided before the LCFS HRI credit provisions were adopted and are, therefore, not addressed or considered in any of these responses. Further synthesis of these results and potentially additional survey responses will be completed in later phases of the project. Ultimately, these data will be leveraged to perform an economic evaluation of the approach of the station network to self-sufficiency in future years and potential recommendations for future policy directions.

Indicators of a Profitable Hydrogen Refueling Station

Responses to the survey largely provided broad agreement on major indicators and requirements for profitable hydrogen refueling stations. Figure 23 provides distributions of responses for these indicators. The necessary minimum daily peak-to-peak fueling capacity for a profitable station appeared to center around 500 kilograms per day. Almost half of respondents indicated stations of 500 to 1,000 kilograms per day could be profitable, while another approximate half indicated stations less than 500 kilograms per day could be profitable. Indications for viable utilization rates (the ratio of daily hydrogen sales to rated maximum throughput for the station design) for these stations were wide-ranging, though all responses were above 50 percent. Some interplay between station capacity and utilization was noted in individual responses; there appeared to be a tendency for respondents with higher minimum station capacity requirements to select a lower minimum utilization rate and vice-versa. This tendency may indicate that the true metric of performance is simply total daily throughput, which was noted to trend toward 400 kilograms per day.

With some ARFVTP-funded hydrogen stations having a design capacity of 500 kilograms per day, a positive interpretation of the survey results related to fueling capacity is that some of these stations may reach a point of self-sufficiency if daily throughput is sufficient, and if cost conditions are met.

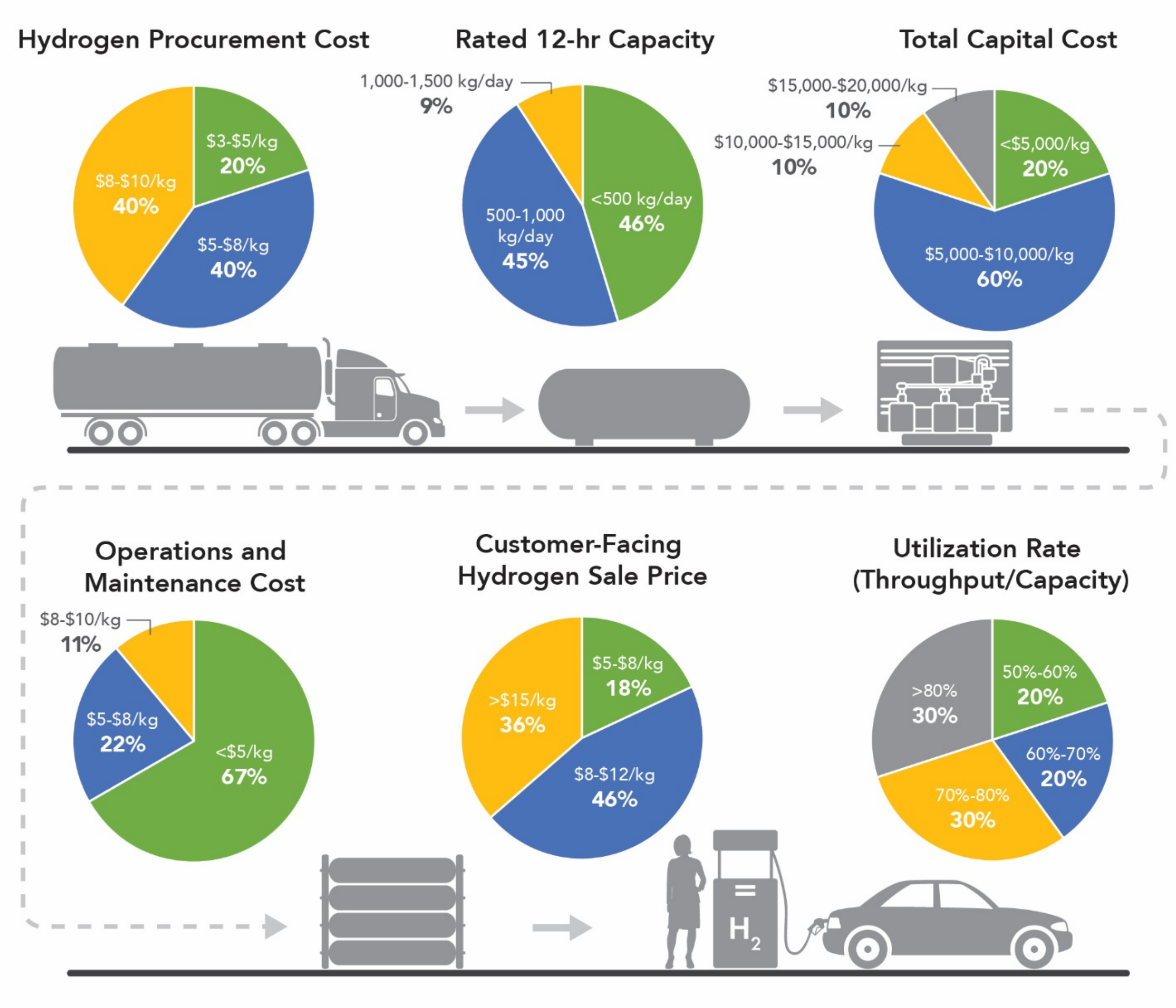
Total capital cost per kilogram tended toward $5,000 to $10,000 per kilogram of installed daily capacity. This range of costs applied equally to stations with liquid and gaseous storage on-site for the long term, while higher costs were indicated for near-term liquid technology. In this context, total capital cost includes site design and engineering, permitting, equipment, project management, and labor costs. Operations and maintenance costs for profitable stations (excluding hydrogen procurement costs) similarly showed strong agreement among respondents, at less than $5 per kilogram.

Costs to procure fuel for a profitable station centered around $8 per kilogram, while sale price to customers at the pump was approximately evenly split between the ranges of $8-$12 per kilogram and greater than $15 per kilogram. However, the latter group of responses seemed to be in line more with present-day stations than a hypothetical future profitable station, with at least one respondent explicitly stating as much. Therefore, it may be possible that industry stakeholders envision there is a potential mix of station cost and throughput characteristics that allow for a profitable business in today's market. When looking across the cost and price indicators in Figure 23 for individual respondents, there are varying degrees of self-consistency (whether respondents tended to choose all high-cost and sale price options, all low-cost and price options, or a mix). Thus, while some respondents may have indicated all low-cost and price options in their responses, the sample size is too small to determine whether there is any significant trend for self-consistency of low (or high) developer and operator costs leading to low (or high) sales price at the pump.

Outside this survey, there also appears to be industrywide consensus that lower customer-facing prices are a necessity, so indications that today's prices are profitable may not be applicable to a longer-term station network vision. Some survey respondents did indicate that today's merchant hydrogen market provides hydrogen to other industries at a significantly lower cost because of the volume and certainty of demand. These responses would imply that a larger station network with substantially higher demand can access much lower prices than are available today for hydrogen as a transportation fuel.

Additional indicators of a profitable station that were provided in open-ended responses included minimum numbers of global station development to achieve capital expense economies of scale, minimum numbers of stations in a similar geographical area (and the definitions of that area) to reduce operational costs, high FCEV deployment volumes and associated station utilization rates, larger capacity stations, liquid hydrogen distribution and on-site station storage, public funding, hydrogen production costs including renewable electricity, and certain taxes.

Figure 23: Industry Survey Responses to Questions About Hypothetical Profitable Stations



Source: CARB

Assessing Investment Opportunities and Competing Forces

Respondents provided a wide range of expectations for financial markers of successful hydrogen refueling network investments. In a widespread hydrogen fueling market scenario, respondents indicated that stations would have to achieve break-even status in as little as 1 year to as much as 10 years. A slight majority seemed to be in agreement with a payback period in the 5-to-10-year period. In terms of internal rate of return (IRR), there did not seem to be agreement on whether the early and developing or the established market would present more stringent expectations. For the early market, respondents indicated that the expectation could be for an IRR that is negative (allowing for early investments that are not individually profitable but may otherwise contribute to long-term success of the company's overall plan) to as high as 20 percent. In a developed and successful market, respondents indicated an IRR between 5 percent and 20 percent could be expected. In a notable number of cases, higher early market IRR was associated with lower long-term IRR and vice versa.

Other key performance indicators that were provided included FCEV population and price, station utilization rate, cost for hydrogen procurement (in general and specific to renewable hydrogen), consistency of public support, and the LCFS credit price. External market signals that could allow investment even at a loss or with lengthened payback periods included FCEV deployment and adoption rates, support for renewable hydrogen procurement, consistent policy support, and assured revenue for installations that produce renewably sourced hydrogen. There was near-unanimous agreement that ancillary services, such as sale of other fuels and convenience store operation, can improve the business case for hydrogen refueling stations, with the overwhelming majority indicating that their business model does not depend on these additional revenue streams.

Some survey respondents indicated that their continued involvement in hydrogen refueling station network development is evaluated against the opportunity costs of participating in other hydrogen fueling markets around the world and in other hydrogen-consuming sectors' business.

Additional Station Design, Operation Details, and Challenges Ahead

Details of station design and cost barriers to successful profit-making station deployment were wide-ranging, so readers are encouraged to consult Appendix C for the group-specific responses received.

A key aspect that seemed to have fairly broad consensus was the expected lifetime of various pieces of equipment at hydrogen refueling stations. In most cases, most items are expected to last between one and two decades, including dispensers, hydrogen storage, chillers, compressors, and point-of-sale devices. The singular standout in responses was nozzles, which were expected to last as little as two to five years.

Respondents in each group provided a wide range of responses related to technical, policy, and permitting barriers to the realization of a profitable business model. Some commonly cited top concerns included a need for consistency and assurance of ongoing public support (especially in the early years of the operation of a station when utilization is low), costs associated with hydrogen production and particularly renewable hydrogen production, and concerns related to varying permitting requirements and expectations across jurisdictions. Due to the breadth of these responses, readers are encouraged to review the group-specific responses in Appendix C for the full discussion of the identified challenges.

CHAPTER 8: Conclusions

Through 2018, the ARFVTP funded $120,077,497 for hydrogen station planning, design, and construction. Of that amount, $109,654,164 funded capital equipment, and $10,423,333 funded O&M. The 64 stations used, on average, $1.9 million of ARFVTP funding per station.

In 2018, the hydrogen refueling station network – composed of 39 open retail stations (38 ARFVTP-funded and 1 privately funded) that cover the San Francisco Bay Area, the Greater Los Angeles Area, Sacramento, and San Diego, with a few connector and destination stations – provides enough fueling capacity for the 5,014 FCEVs registered with the California DMV as of October 2018. With roughly one-third of the stations in Northern California and two-thirds in Southern California, and the connector and destination stations, drivers can fill up and drive throughout much of the state.

Network coverage grew when seven new open retail stations and one privately funded (upgrade) station came on-line. As of December 2018, another 26 stations are in development. The California hydrogen refueling network has 12 of the 64 ARFVTP-funded stations in disadvantaged communities, covering 35 percent of California's disadvantaged community population.

The use of liquid hydrogen instead of gaseous hydrogen started in 2010 at some sites and expanded this year by 12 stations, which will become open retail in the 2019-2020 time frame. Liquid hydrogen may be more suitable for higher-capacity stations, and by adding liquid hydrogen stations to the network, the overall network capacity increased by nearly 2,000 kilograms per day, from 15,000 kilograms to 17,000 kilograms per day. Depending on where FCEV drivers fuel, at any given point in time, and their fueling preferences, the capacity is enough to fill the FCEVs on California's roads today.

The amended LCFS regulations, which include a new provision for HRI credit generation, provide a significant opportunity for hydrogen refueling station owners to obtain an assured revenue stream to offset cost during the early, low-utilization period of a hydrogen refueling station. For example, Energy Commission staff estimates the potential LCFS revenue for a 180–kilogram-per-day hydrogen refueling station over a 15-year period is $1.14 million, with nearly $690,000 from dispensing credits and $450,000 from HRI credits. Energy Commission staff estimates that a hydrogen refueling station with a 1,200–kilogram-per-day fueling capacity could generate nearly $5.25 million over 15 years, with nearly $3.12 million from dispensing credits and $2.13 million from HRI credits. (These estimates are based on several assumptions made by Energy Commission staff that were selected to run hypothetical scenarios.) The extent to which this potential revenue from the LCFS will attract more private investments into station development remains to be determined.

The potential of the HRI credits also may influence how long it takes for hydrogen refueling stations to become self-sufficient. Survey results from CARB and the Energy Commission's self-sufficiency study indicate that a combination of factors, including station throughput and capital and operating costs, need to align for stations to become profitable. Stations with nameplate capacity of 500 kilograms per day – which is the capacity of some funded stations – may reach self-sufficiency. CARB and the Energy Commission will assess this potential in next year's joint report.

Emissions reductions increase when more FCEVs are driven. Actual CO_2e reductions attributable to hydrogen refueling stations operated in California are nearly 6,000 metric tons[52] in 2018, and this could potentially rise twelvefold by 2024. Regionally, the Greater Los Angeles Area ranks the highest in terms of emissions reductions, with the San Francisco Bay Area a close second.

Lighting and signage remain integral to station operations. State and local requirements set guidance for station developers with the station user in mind. For example, the Caltrans Traffic Operations Policy Directive and the fact sheet on signage, both easily accessible by the public, provide the details for state highway system signage. Future solicitations may consider other ways in which the customer experience at hydrogen refueling stations can be enhanced.

The 5,014 FCEVs registered with the DMV as of October are double the 2,473 registered at the same time last year. Today's FCEV deployment of 5,658 (as of December 1, 2018) is up from 3,234 reported at the same time last year. The results of the 2018 CARB survey show 23,600 FCEVs projected by 2021and 47,200 FCEVs projected by 2024. The 2024 projections reflect growth of nearly 10,000 FCEVs over last year's projections made for the previous years: 13,400 FCEVs by 2020 and 37,400 FCEVs by 2023. The latest projections are a positive sign that auto manufacturers anticipate faster market growth than they did one year ago. If industry stakeholders focus on building driver confidence by improving the reliability of hydrogen refueling stations and the hydrogen supply chain, these efforts may bolster the number of FCEVs deployed. Raising this confidence level could produce a cycle of more stations creating more FCEV demand, which requires more stations to be built. All industry members play a part in achieving this type of market success.

The continued decrease in time required to develop a station, as observed in 2018, could be attributable, at least in part, to the Energy Commission's stewardship of the funding solicitations. This stewardship includes the solicitation design. The most recent solicitation, GFO-15-605, included critical milestones connected to AHJ outreach and site control. For stations funded under GFO-15-605, the average time spent completing the first phase of development (start of the Energy Commission grant-funded project to the initial permit application filing) was 85 percent less than the time spent by station developers funded under the previous solicitation. This improvement cannot be overstated because it has the large potential of leading to quicker station completion. The influence of the critical milestones on

52 A metric ton is a unit of weight equal to 1,000 kilograms.

the rest of the station development phases remains to be determined as station development progresses in 2019.

The amount of timing and growth needed to meet the projected fueling demand reflects regional differences. The Greater Los Angeles Area ranks the highest for projected fueling demand by 2024, with the San Francisco Bay Area, San Diego, and Sacramento areas following.

The remaining cost required to establish a network of 100 stations will likely decrease depending on the degree to which the proposed funding strategy in the Hydrogen Draft Solicitation Concepts achieves economies of scale and the LCFS updates enable station development with fewer ARFVTP dollars per station. The time required to reach the 100 stations remains the same as reported in 2017, namely to 2024.

As underscored in last year's joint report, the analysis presented hinges on the FCEV market and the station network growing simultaneously. In addition to capacity, FCEV market growth depends on the expansion of station network coverage. Tomorrow's fueling demand offers more business opportunities, a more dynamic fueling network, and happier FCEV drivers in California. As always, communication remains key. Stakeholders inform policy, and policy meets stakeholder aspirations.

APPENDIX A: Hydrogen Refueling Station Financial Assessment

This appendix presents financial assessments of hydrogen refueling stations to inform investors and interested stakeholders about financial metrics for making investment decisions. Public support remains needed to create an attractive private investment opportunity.

The following financial assessments for hydrogen refueling stations represent output from the Hydrogen Financial Analysis Scenario Tool (H2FAST).[53] These financial assessments detail cash flow per kilogram of hydrogen and account for station capital equipment costs, O&M costs, upfront financing, and key financial parameters based on conversations with station developers, Energy Commission grant agreement budgets and invoices, and the station developers' input to the NREL Data Collection Tool.[54]

Table A-1: Summary of Key Financial Metrics for Three Hydrogen Refueling Station Designs

Station	Levelized Break-Even Price of H2 (per kg)	Net Present Value (NPV)	Leveraged After-Tax Nominal Internal Rate of Return (IRR)
200 kg/day gaseous truck delivery connector/destination with slow (seven-year) growth in utilization	$11.00	$123,000	14.4 percent
400 kg/day gaseous truck delivery with fast (four-year) growth in utilization	$9.00	$959,000	25.8 percent
600 kg/day delivered liquid with fast (six-year) growth in utilization	$9.00	$1,506,000	36.9 percent

Source: NREL

Figures A-1, A-2, and A-3 show the financial assessments for the three station designs. The assessments are based on a 20-year station life expectancy, but not all components are expected to perform continuously for 20 years without regular maintenance, component replacements, and overhauls.

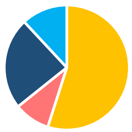
53 Information on H2FAST is available at https://www.nrel.gov/hydrogen/h2fast/.

54 The NREL Data Collection Tool template is found at http://www.energy.ca.gov/contracts/GFO-15-605/Attachment-11_NREL_Data_Collection_Tool_2016-06-02.xlsx.

Figure A-1: Financial Assessment, 200 kg/day Connector/Destination Station

(1) 200 kg/d Connector/Destination Station

Up-front financing estimate by source



CEC funding	$	1,500,000
Equity (estimate)	$	666,667
Debt (estimate)	$	333,333
Total capital cost	**$**	**2,500,000**
CEC O&M support	$	300,000
Private financing / CEC financing ($/$)		0.22

Key financial parameters

First year retail price of H2 ($/kg)	$	15.31
Levelized retail price of H2 ($/kg)	$	10.61
First year cost of delivered H2 ($/kg)	$	8.94
Levelized cost of delivered H2 ($/kg)	$	6.60
Variable electricity use (kWh/kg)		4.00
Fixed electricity use (kW)		2.00
First year electricity demand & service charges ($/year)	$	2,100
Levelized cost of electricity ($/kWh)	$	0.230
First year rent ($/year)	$	46,000
First year maintenance ($/year)	$	44,600
Purity testing ($/year	$	8,100
Internet connection ($/year)	$	2,300

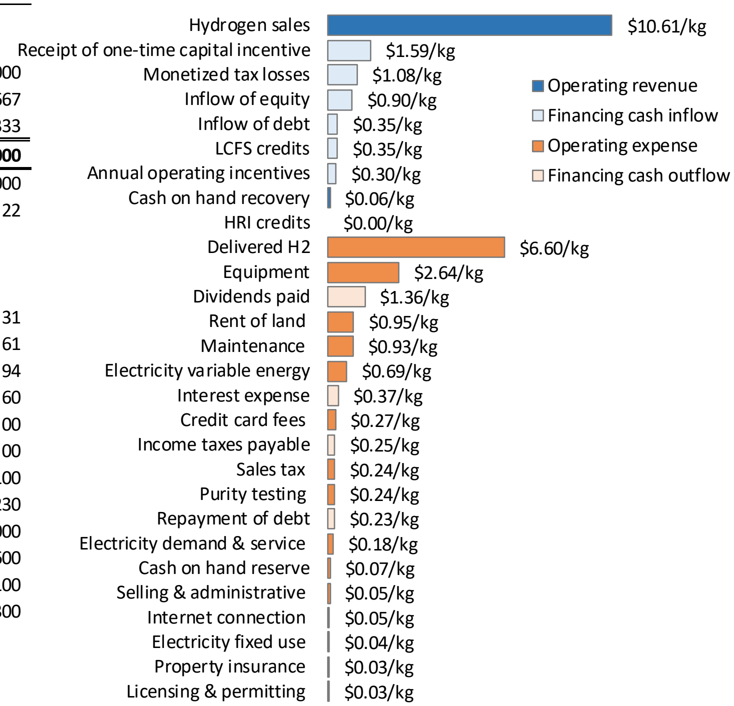
Key assumptions

Nameplate capacity (kg/day)	200
Project initiation year	2018
Equipment operational life (years)	20
Long term equipment utilization	80%
Demand ramp-up period (years)	7.0

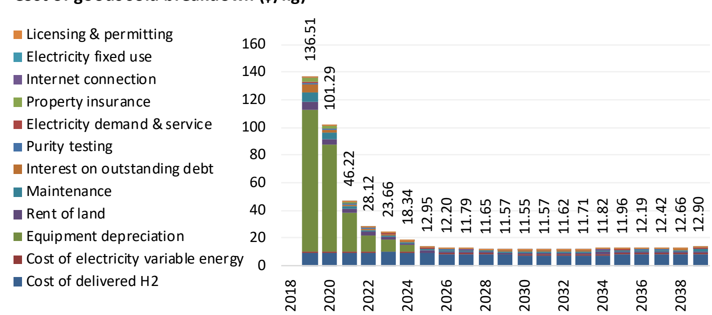
Financial performance and break-even retail price

Levelized break-even price of hydrogen ($/kg)		$10.53
Levelized retail margin ($/kg)	$	3.32
Levelized break-even margin ($/kg)	$	3.25
Project NPV	$	123,000
Profitability index		1.66
Leveraged after-tax nominal IRR		14.4%

Real levelized value breakdown of hydrogen ($/kg)



Cost of goods sold breakdown ($/kg)

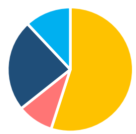


Source: NREL

Figure A-2: Financial Assessment, 400 kg/day Gaseous Truck Delivery Station

(2) 400 kg/d Station (gas delivery)

Up-front financing estimate by source



CEC funding	$	1,800,000
Equity (estimate)	$	800,000
Debt (estimate)	$	400,000
Total capital cost	**$**	**3,000,000**
CEC O&M support	$	300,000
Private financing / CEC financing ($/$)		0.22

Key financial parameters

First year retail price of H2 ($/kg)	$	15.31
Levelized retail price of H2 ($/kg)	$	10.82
First year cost of delivered H2 ($/kg)	$	8.94
Levelized cost of delivered H2 ($/kg)	$	6.77
Variable electricity use (kWh/kg)		4.00
Fixed electricity use (kW)		2.00
First year electricity demand & service charges ($/year)	$	2,100
Levelized cost of electricity ($/kWh)	$	0.199
First year rent ($/year)	$	46,000
First year maintenance ($/year)	$	53,500
Purity testing ($/year	$	8,100
Internet connection ($/year)	$	2,300

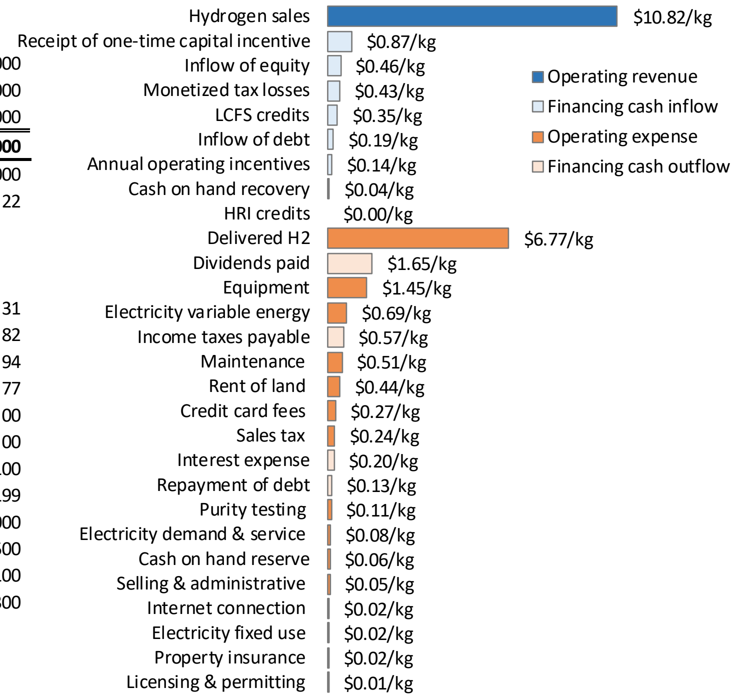
Key assumptions

Nameplate capacity (kg/day)	400
Project initiation year	2018
Equipment operational life (years)	20
Long term equipment utilization	80%
Demand ramp-up period (years)	4.0

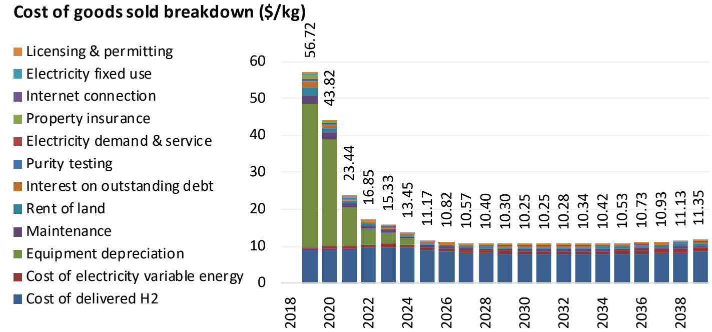
Financial performance and break-even retail price

Levelized break-even price of hydrogen ($/kg)		$9.41
Levelized retail margin ($/kg)	$	3.36
Levelized break-even margin ($/kg)	$	1.96
Project NPV	$	959,000
Profitability index		4.07
Leveraged after-tax nominal IRR		25.8%

Real levelized value breakdown of hydrogen ($/kg)



Cost of goods sold breakdown ($/kg)

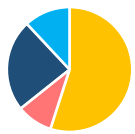


Source: NREL

Figure A-3: Financial Assessment, 600 kg/day Liquid Truck Delivery Station

(3) 600 kg/d Station (liquid delivery)

Up-front financing estimate by source



CEC funding	$	2,625,000
Equity (estimate)	$	583,333
Debt (estimate)	$	291,667
Total capital cost	**$**	**3,500,000**
CEC O&M support	$	300,000
Private financing / CEC financing ($/$)		0.11

Key financial parameters

First year retail price of H2 ($/kg)	$	15.31
Levelized retail price of H2 ($/kg)	$	10.67
First year cost of delivered H2 ($/kg)	$	8.94
Levelized cost of delivered H2 ($/kg)	$	6.65
Variable electricity use (kWh/kg)		4.00
Fixed electricity use (kW)		2.00
First year electricity demand & service charges ($/year)	$	2,100
Levelized cost of electricity ($/kWh)	$	0.191
First year rent ($/year)	$	46,000
First year maintenance ($/year)	$	113,600
Purity testing ($/year	$	8,100
Internet connection ($/year)	$	2,300

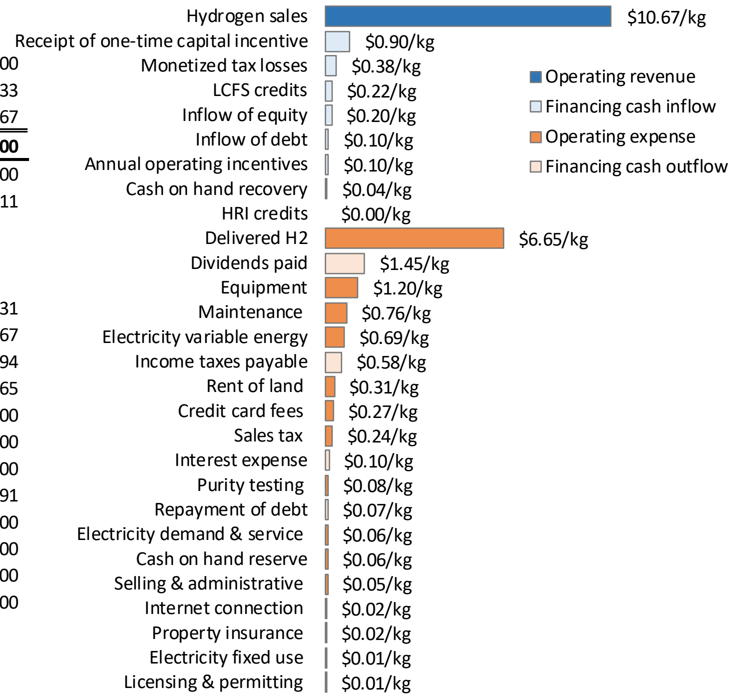
Key assumptions

Nameplate capacity (kg/day)	600
Project initiation year	2018
Equipment operational life (years)	20
Long term equipment utilization	80%
Demand ramp-up period (years)	6.0

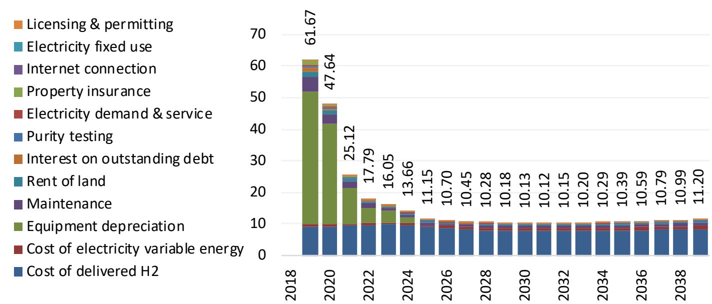
Financial performance and break-even retail price

Levelized break-even price of hydrogen ($/kg)		$8.92
Levelized retail margin ($/kg)	$	3.33
Levelized break-even margin ($/kg)	$	1.58
Project NPV	$	1,506,000
Profitability index		7.24
Leveraged after-tax nominal IRR		36.9%

Real levelized value breakdown of hydrogen ($/kg)



Cost of goods sold breakdown ($/kg)



Source: NREL

APPENDIX B: Fueling Trends

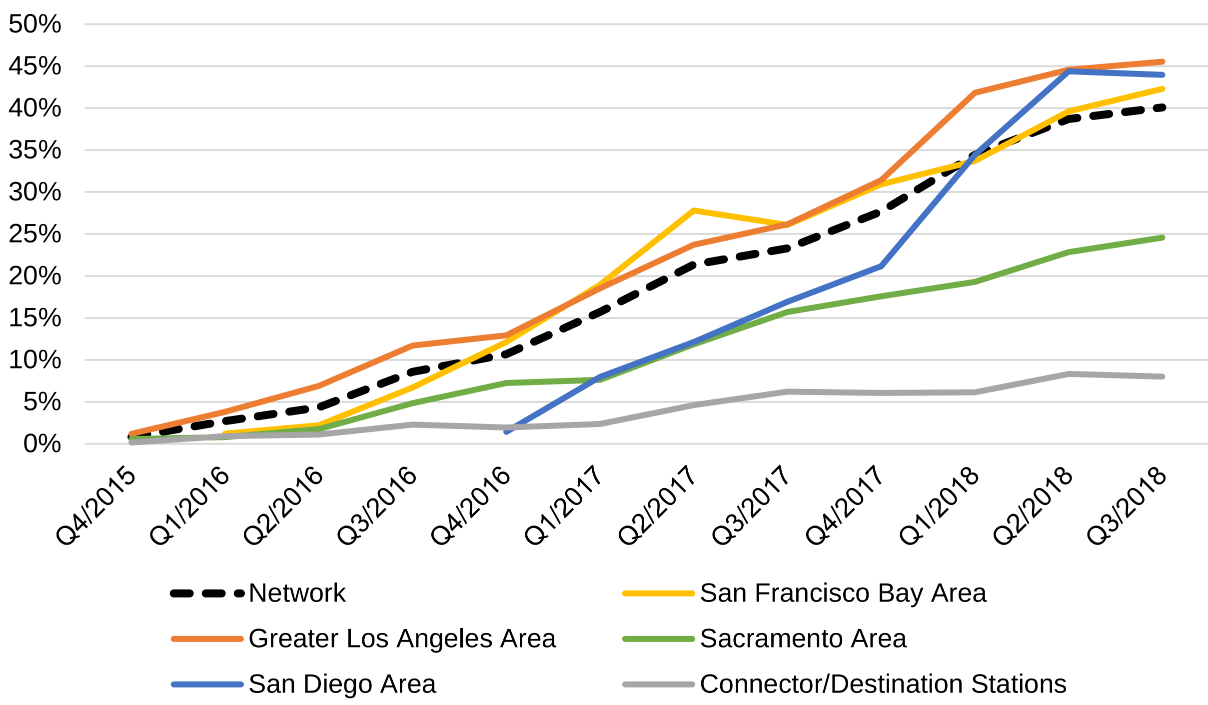
This appendix presents the throughput and dispensing information from open retail stations to evaluate station usage and performance. The fueling trends data allow the Energy Commission staff to assess the efficacy of station siting and technology.

The following tables and figures depict fueling trends for the actual use of California's hydrogen refueling station network. The Energy Commission obtains quarterly data from the station operators, and NREL compiles and analyzes the data. Some figures present information according to the final fill pressure of fuel dispensed: H35 or at H70. H35 dispenses hydrogen to fuel cell electric vehicles at a 350 bar pressure. H35 also is the pressure most commonly used by fuel cell transit buses. H70 dispenses hydrogen to fuel cell electric vehicles at a 700 bar pressure and -40 degrees Celsius.

Quarterly Trends

Figure B-1 shows the statewide network utilization by region. The network average utilization rate increased from 28 to 40 percent from the fourth quarter of 2017 to the third quarter of 2018. The San Diego area experienced the highest rate of growth in utilization from the fourth quarter of 2017 to the third quarter of 2018.

Figure B-1: Quarterly Hydrogen Station Utilization, H70 and H35



Source: California Energy Commission

Figure B-2 summarizes the station use based on quarterly average kilograms dispensed relative to the nameplate capacity of the station (dispensed kilograms/capacity kilograms). The figure shows station count by quarterly average utilization in 10 percent increments with a cap of 100 percent. The 2017 Joint Report presented that no station had greater than 80 percent utilization on average. As of the third quarter of 2018, two stations had greater than 90 percent utilization on average.

The black box in each quarter represents which 10 percent increment was the overall network average. The corresponding average utilization rate is specified in the row of black boxes at the bottom of the figure.

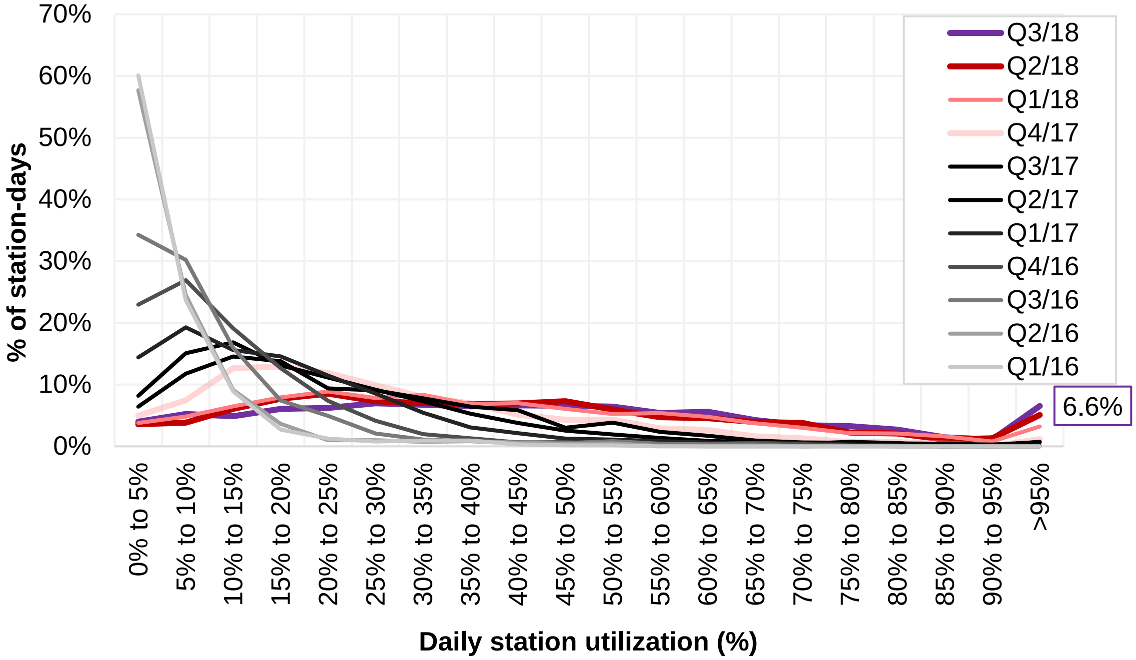
Figure B-2: Number of Stations by Level of Utilization and Quarter

Utilization	Q1 16	Q2 16	Q3 16	Q4 16	Q1 17	Q2 17	Q3 17	Q4 17	Q1 18	Q2 18	Q3 18
0% to 10%	13	18	16	14	10	6	9	5	8	4	5
10% to 20%	1	1	4	8	8	9	7	8	3	6	6
20% to 30%		1		2	5	6	5	6	6	5	3
30% to 40%					1	5	5	3	4	3	3
40% to 50%			1	1	1		3	6	3	5	5
50% to 60%					1	1	1	2	4	5	5
60% to 70%									2	3	3
70% to 80%						1	1	1	2	1	2
80% to 90%										1	
90% to 100%									1	1	2
Station count	14	20	21	25	26	28	31	31	33	34	34
Average util.	3%	5%	9%	11%	16%	21%	23%	26%	33%	37%	38%

Source: NREL

Figure B-3 shows the distribution of daily utilization across the network according to the number of days that each station operated within the indicated utilization ranges. In the third quarter of 2018, 6.6 percent of the station-days were spent at or above the nameplate capacity of the stations, which is an increase from 0.9 percent reported in the 2017 Joint Report.

Figure B-3: Percentage of Station-Days by Utilization Rate



Source: NREL

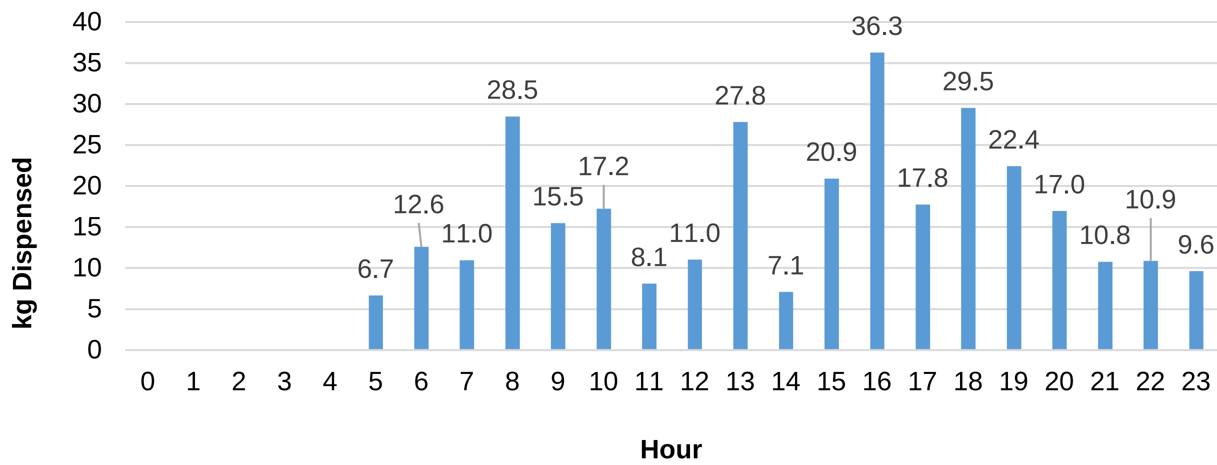
One of the stations achieving more than 100 percent utilization shown in Figure B-3 is the UC Irvine station.[55] The station has the greatest throughput and was the most used station in California in 2018. In the third quarter of 2018, the station dispensed more than 18,500 kilograms of hydrogen over 6,180 fueling events. In the same quarter, the statewide average dispensing per station was more than 7,200 kilograms with an average of 2,248 fueling events.

This station fills a fuel cell electric bus daily. The filling occurs between 10 p.m. and 2 a.m., when light-duty FCEVs are unlikely to use the station.

Figure B-4 shows one day of dispensing for the UC Irvine station (August 3, 2018), when the station dispensed a record 320 kilograms, which was roughly 12 percent of total network dispensing that day and was 178 percent of the 180-kilogram-per-day station nameplate capacity.

55 UCI plans to increase the daily capacity of the station from 180 kilograms per day to 800 kilograms per day by changing from gaseous hydrogen to liquid hydrogen and adding a second hydrogen dispenser for simultaneous refueling of two FCEVs. The planned upgrade will have four fueling positions.

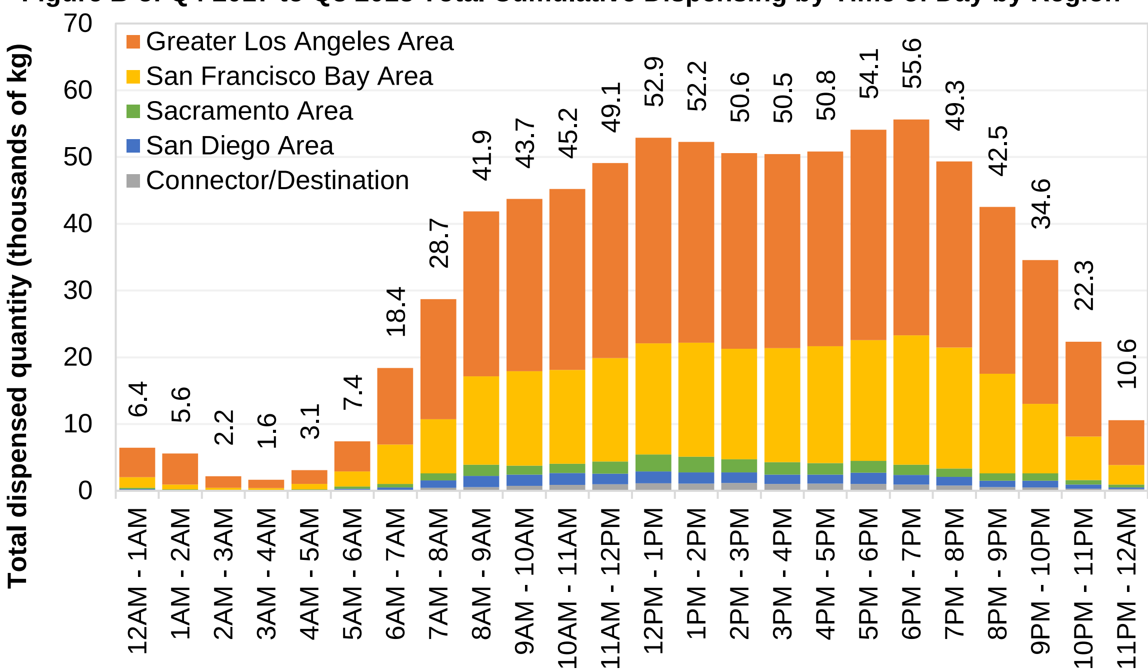
Figure B-4: Record Day Dispensing for the UC Irvine Station



Source: California Energy Commission

Figure B-5 shows the cumulative hourly amount of fuel dispensed in the California network from the fourth quarter of 2017 to the third quarter of 2018. The highest amount of dispensing occurred between 6 p.m. and 7 p.m., and the lowest amount of dispensing occurred between 3 a.m. and 4 a.m. The fueling trends are very close to those seen the year prior.

Figure B-5: Q4 2017 to Q3 2018 Total Cumulative Dispensing by Time of Day by Region



Source: NREL

Figures B-6 through B-9 show regional analyses of average and maximum dispensing by time of day based on data from the third quarter of 2018.

Figure B-6: Greater Los Angeles Area
Q3 2018 Fueling by Time of Day

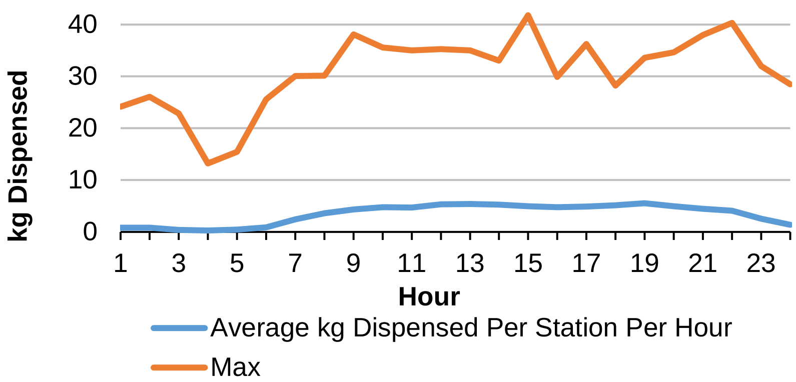


Figure B-7: San Francisco Bay Area
Q3 2018 Fueling by Time of Day

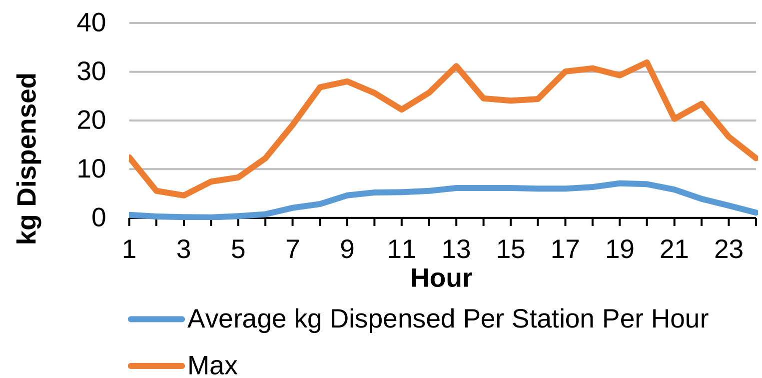


Figure B-8: San Diego Area
Q3 2018 Fueling by Time of Day

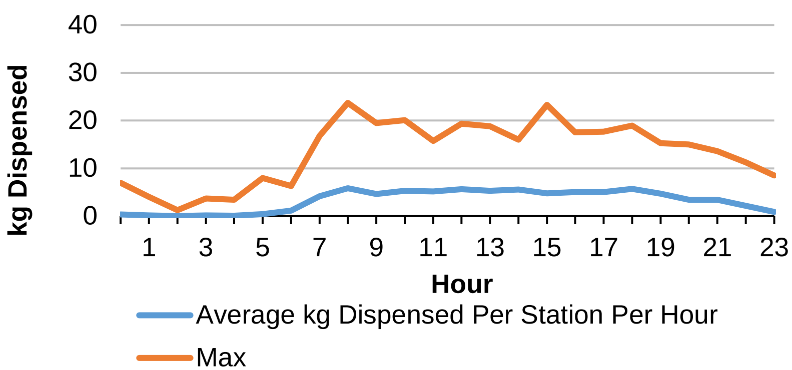
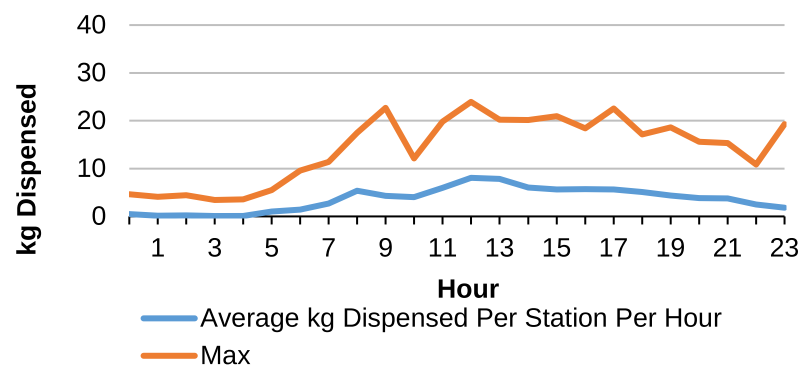


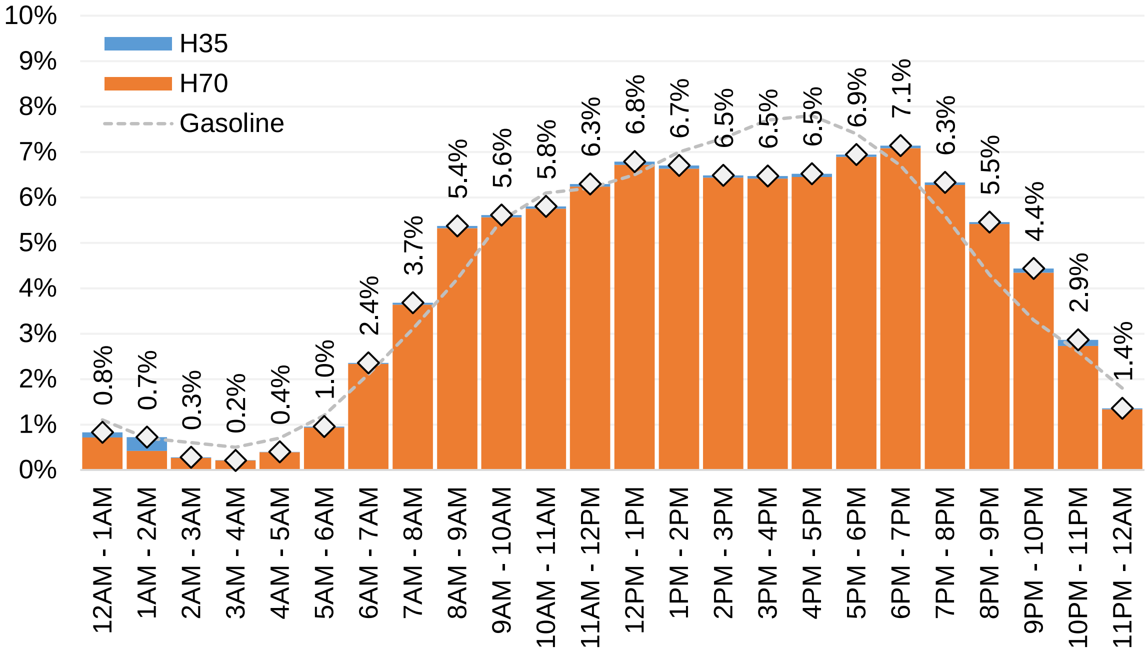
Figure B-9: Sacramento Area
Q3 2018 Fueling by Time of Day



Source: California Energy Commission

Figure B-10 compares the time–of-day use for hydrogen to gasoline refueling. The gasoline usage dotted line uses data from the "Chevron Profile."[56] Most dispensing of hydrogen occurred in the early evening, and the least between 2 a.m. and 5 a.m. This trend is similar to that of the year prior. Figure B-10 shows the hydrogen dispensing profile follows the gasoline dispensing profile closely. One noticeable difference is that the afternoon peak is not as prominent for hydrogen as it is for gasoline and appears to occur slightly later in the evening. This is a positive sign that FCEV drivers' fueling behavior is close to those driving gasoline-fueled vehicles.

Figure B-10: Q4 2017 to Q3 2018 Fueling Events by Time of Day Compared With Gasoline

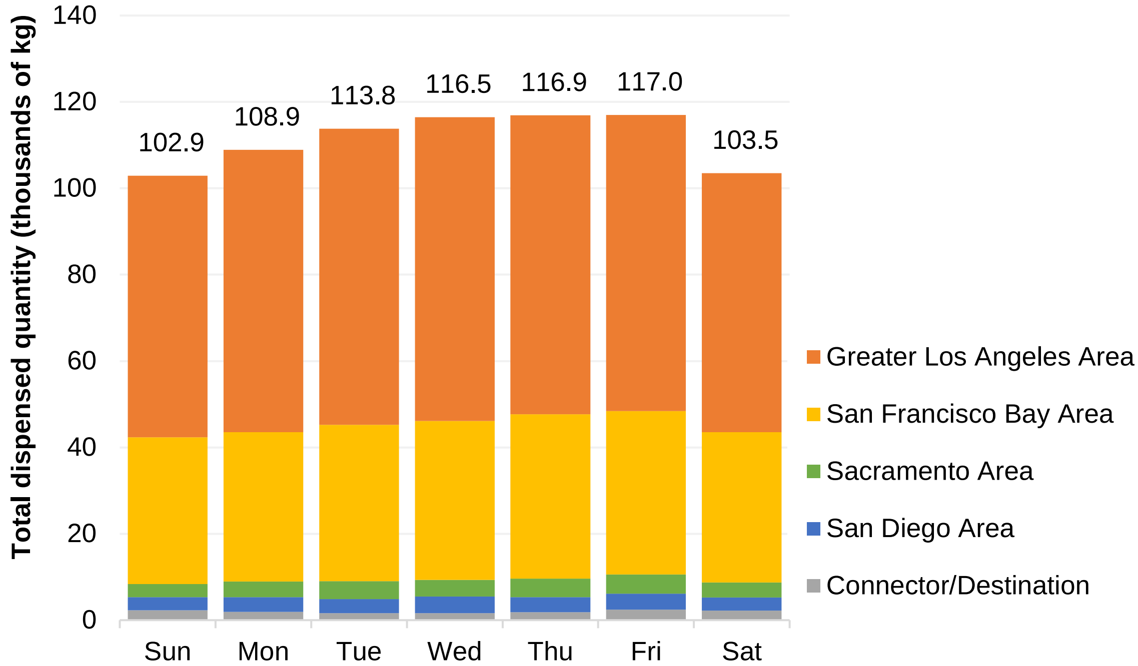


Source: NREL

Figure B-11 shows the total dispensing per day of the week between the fourth quarter of 2017 and the third quarter of 2018. The chart shows more dispensing occurring toward the end of the workweek. The amount of dispensing is almost double the amount reported last year, but the day-of-week pattern remains similar.

56 The *Chevron Profile* is a profile developed based on fuel dispensing data from gas stations provided by Chevron. Source: Chen, Tan-Ping. *Final Report: Hydrogen Delivery Infrastructure Options Analysis.* Nexant. DOE Award Number: DE-FG36-05GO15032. http://energy.gov/sites/prod/files/2014/03/f11/delivery_infrastructure_analysis.pdf and https://www.energy.gov/sites/prod/files/2014/03/f9/nexant_h2a.pdf.

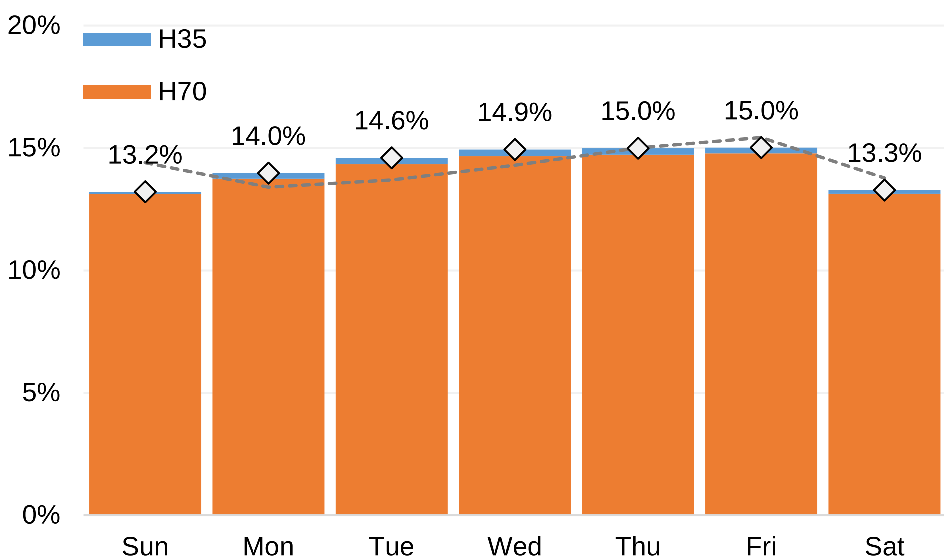
Figure B-11: Q4 2017 to Q3 2018 Total Cumulative Dispensing by Day of Week by Region



Source: NREL

Figure B-12 shows the percentage of station network fueling events by day of week compared with gasoline, again using the Chevron Profile. Similar to last year, most dispensing occurred on Wednesdays, Thursdays, and Fridays, and the least occurred on the weekends. And there continues to be positive correlation between the demand for H35 and H70, in that the days of the week with more H70 fueling events also tend to have more H35 fueling events.

Figure B-12: Q4 2017 to Q3 2018 Fueling Events by Day of Week Compared With Gasoline



Source: NREL

APPENDIX C: Self-Sufficiency Survey Vignettes

Chapter 7 provided an overview of all self-sufficiency survey responses, inclusive of all entries in all groups of respondents. This appendix provides group-specific vignettes. This appendix reports only groups with a response rate high enough to ensure confidentiality of individual responses could be protected. The vignettes included are from industrial gas companies (IGC), equipment providers, and independent station operators.

Industrial Gas Company (IGC) Vignette

IGC companies responded with an 80 percent response rate. Not all questions were answered by all respondents. A wide variety of company sizes and business models are represented, all operating more than a decade. Respondent companies varied in size, supplying hydrogen to as many as 30 light-duty vehicle hydrogen refueling stations in California, 10 in the rest of the United States, and 45 in the rest of the world. The total number of hydrogen refueling stations either owned or operated by each company is up to 5 in California, 10 in the rest of the United States, and 40 in the rest of the world. The number of stations in development was up to two in California, one in the rest of the United States, and three in the rest of the world. The number of stations that are operating with station equipment originally manufactured by the responding companies was up to almost 30 in California, 10 in the rest of the United States, and 100 in the rest of the world. Companies differed in regional priorities, and not all companies are active in directly owning, operating, or developing stations.

The total hydrogen supplied to hydrogen refueling stations annually by each of the responding companies was up to 30 metric tons of hydrogen per year for California, 4 tons for the rest of the United States, and 300 tons for the rest of the world. The total amount of hydrogen supplied to end-use customers including all other merchant or industrial uses was not reported for California but was 500 to 9,000 metric tons per year in the rest of the United States. Not all respondents reported hydrogen sales outside the United States, but responses received were as high as millions of tons of hydrogen per year for the rest of the world.

Indicators of a Profitable Hydrogen Refueling Station

When asked about minimum market conditions required to make a profit, respondents indicated that regardless of stations size (up to 1,000 kilograms per day), at least 400 kilograms per day would be required. This result came about when respondents were asked about minimum utilization rates for profitability. Smaller stations stated a slightly higher utilization level than larger stations. Total capital costs needed would be $5,000 to $10,000 per kilogram of installed capacity for gaseous storage facilities and $10,000 to $15,000 per kilogram for liquid. An eventual long-term target of $5,000 to $10,000 per kilogram would be viable for liquid facilities.

Respondents indicated that retail customers would need to pay between $8 and $12 per kilogram of hydrogen at the pump, with one outlier indicating that $15 per kilogram would be required. The cost to procure fuel (delivered to site) ranged from $5 to $10 per kilogram, but most were less than $8 per kilogram. Operations and maintenance costs were less than $5 per kilogram dispensed. Comments indicated that these targets would need to be reached within three years of operation, during which period a subsidy would be needed to survive.

Investment Opportunities

The cost of acquiring a customer is much higher in the hydrogen transport sector than the merchant sector. Assuming widespread market adoption of FCEVs, a new station should break even in one to two years. External market signals listed are the existence of more cars and government subsidies.

To invest in hydrogen for transportation fueling, the investment must stand on its own according to corporate profit requirements. A typical expected return for early market light-duty vehicle refueling infrastructure investments would be an IRR of 12 to 20 percent. Once the market is developed, an IRR of 15 to 20 percent is expected. Other nonhydrogen and hydrogen related investments must achieve an IRR of 15 percent.

Key performance indicators used to measure the success (or failure) of an investment would be station utilization of at least 80 percent achieved in one to three years, renewable hydrogen cost of less than $10 per kilogram at the pump achieved eventually, an IRR of 15 percent or greater achieved in 10 to 15 years, and station profitability from Day One.

Competing Forces

Respondents indicated that the light-duty vehicle fueling business is 0.1 to 2 percent of the total hydrogen or nonhydrogen-related business. All respondents indicated that there is internal competition with other programs/revenue types. Most companies did not have a business model that depended on ancillary services or income.

Additional Station Design and Operation Details

Expected station component lifetimes typically centered around a decade with exceptions for nozzles (two years) and hydrogen storage (two decades). Respondents provided somewhat overlapping information on design limitations for gaseous or liquid distribution and storage of light-duty vehicle stations. Gaseous was indicated as appropriate for station capacities less than 3,500 kilograms per day, while liquid was appropriate for capacities equal to or greater than 1,000 kilograms per day.

Respondents indicated on average that the relative costs of hydrogen compression were 3 percent for liquid storage designs and 5 to 10 percent for gaseous designs. However, one respondent reported far higher estimates for both types, raising the possibility that the question may have been interpreted differently or a different scope was assumed. Other advantages or disadvantages for liquid versus gaseous storage/delivery were that liquid offers lower delivery costs, lower operations costs, and a better potential to meet station total cost of ownership targets. It was noted that gaseous requires smaller setbacks for station layout but also has a smaller throughput capacity.

Challenges Ahead

Respondents were asked about barriers to success or profitability for stations from the perspective of IGCs, and the following describes some challenges.

- Rent was indicated as a large operating cost that needs to drop from $4,000 per month to $2,500 per month to attain profitability.
- Power/electricity costs need to drop from $2,000 per month to $500 per month.
- Labor and parts need to be reduced from $50,000 to $60,000 per year per station to $25,000 to $30,000 per year.
- Replacement nozzles costs need reduction by 25 percent, valves by 50 percent, gas detection equipment by 25 percent, and maintenance costs per kilogram by 50 to 60 percent. Total capital costs for station equipment should come down by 33 to 50 percent.
- Technical barriers raised by respondents are high hydrogen production costs and the low number of equipment providers available.
- Policy barriers included the large liquid hydrogen setback requirements for station layout, the renewable hydrogen requirements, and the lack of assurance for hydrogen demand beyond three to five years.
- Development and permitting barriers included the already mentioned liquid hydrogen permits required, NIMBY concerns, and differing permitting requirements by region.

Hydrogen Supply Chain Market Potential

Key market potential, in terms of amount of hydrogen produced and sold, and market share targets are business confidential and cannot be reported. However, respondents did indicate that selling hydrogen to light-duty vehicle fueling stations represented from 30 to 80 percent of their company's business, that the target profit margin is 20 percent, and that hydrogen light-duty vehicle fueling equipment sales would need to be in excess of 30 to 100 units (equipment for one station) per year to make a profit. Current fueling equipment production rates centered around 50 units per year.

Most respondents indicated that the 33 percent renewable requirement for hydrogen supply was a large problem (as compared to small problem or not a problem at all). One response indicated that it posed no problem at all, but with a few "it depends" added on, that amounted to it being a problem after all. The cost of the renewables was pointed to as a factor, the definition of what a renewable source for hydrogen can be is too restrictive, and subsequently qualifying for the LCFS credits was difficult. The favorite cost-effective renewable pathway for hydrogen production was liquefied SMR of green energy sources initially to all electrolysis eventually. Respondents felt that green biogas SMR could attain $8 per kilogram as a production cost within 5 years, $5 to 6 per kilogram in 10 years, and eventually $1.5 to 2.5 per kilogram in 20 years (after a full transition to electrolysis).

Equipment Provider Vignette

Companies that were surveyed produce a variety of hydrogen refueling station equipment, including electrolyzers, compressors, chillers, high-pressure storage, heat exchangers, dispensers, and point-of-sale systems.

Surveys sent to equipment providers were returned with an 80 percent response rate. Not all questions were answered by all respondents. The companies have all been involved in hydrogen station equipment production for more than a decade. Some companies have multiple decades of experience, even approaching a century of involvement in the industry. While all companies provide equipment for hydrogen refueling station development, not all are active in directly owning, operating, or developing stations or a combination of these. These companies' presence as direct station developers in California is limited to a single station; none are active in the United States outside California, but they collectively have greater activity in other countries (with roughly 30 stations in operation and 10 in development). However, as equipment suppliers, these companies have substantial involvement in all geographies. Companies have supplied components to as many as 10 stations in California, 5 stations in other states outside California, and 35 stations in other countries outside the United States.

Indicators of a Profitable Hydrogen Refueling Station

Respondents reported that stations as large as 500 to 1,000 kilograms per 12-hour peak-to-peak design capacity may be necessary to enable profitable operations. Respondents agreed that the utilization rate (ratio of throughput to design capacity) would need to be in the range of 70 to 80 percent. These stations would likely store hydrogen on-site as a gas and could be profitable with capital costs up to $10,000 per kilogram of installed capacity. Operations and maintenance would need to be below $5 per kilogram, though there were indications of a preference for low costs per kilogram. Hydrogen procurement costs (whether produced on-site or delivered from a central plant) could range from $3 to $8 per kilogram in these situations, with an expectation of the sale price to the consumer in the range of $5 to $12 per kilogram and an eye toward cost parity (on a dollar-per-mile basis) with conventional fossil fuels.

Respondents provided insights on several additional considerations that could be requirements for stations to return a profit. These considerations included continued participation of public funding, assurance of FCEV deployment volumes, low-cost (grid-tied) renewable electricity rate structures to enable affordable low-carbon hydrogen production, and exemptions to certain taxes for equipment and fuel procurement.

Assessing Investment Opportunities

Respondents indicated that a future market with widespread FCEVs would require stations to break even on the initial investment in as few as 3 years to as many as 10 years. In terms of internal rate of return, respondents anticipate near-term stations will provide negative returns, but a fully realized network of stations would provide returns similar to other institutional investments between 5 and 10 percent.

Respondents cited external signals from the FCEV market and public support for hydrogen station funding and renewable hydrogen energy storage (through electrolysis) as factors in their investment decision-making process.

Respondents did not provide agreement on whether ancillary services and operations can be leveraged to improve the business case at individual stations, but all respondents indicated these additional revenue streams are not a mandatory aspect of their business model. Respondents indicated on-site hydrogen production, heavy-duty vehicle fueling, and grid-tied load shifting as potential supplementary revenue streams.

Competing Forces

Competing opportunities in other markets around the globe and for other transportation sectors or industrial applications can represent opportunity costs to developers of light-duty fueling stations. Internally, hydrogen refueling stations represent 40 to 45 percent of these companies' hydrogen-related business, which is equivalent to the proportion of their total hydrogen and nonhydrogen business. Hydrogen refueling stations for light-duty vehicles were confirmed to compete against other hydrogen-related ventures within the company.

Companies did and did not report that their light-duty hydrogen refueling station business ventures must recover early sunk costs. Respondents also did not agree on whether the market for hydrogen equipment for light-duty vehicle fueling stations is considered compared to the market for similar equipment in the fossil fuel refining industry. However, for respondents that indicated such comparisons were considered in their decisions, they indicated that the market for equipment for hydrogen refueling stations must prove as profitable as equipment for fossil fuel refining.

Additional Station Design and Operation Details

Expected station component lifetime typically ranged from one to two decades with the exception of nozzles, which were reported to be expected to last for three to five years. Respondents indicated some expected overlap in hydrogen storage phase as a function of daily dispensing capacity. Gaseous stations were envisioned as most appropriate for stations from 100 to as large as 2,400 kilograms per day, while liquid stations were reported as appropriate for 1,000 kilograms per day and larger.

Respondents did not have clear insight on compression costs for liquid stations, but there was general agreement that roughly 10 percent of the cost to deliver hydrogen to the consumer at a gaseous station could be attributed to compression. Zoning and setback issues with liquid hydrogen storage, including when the tank is designed to be buried, were cited as potential difficulties to adopting the technology.

Challenges Ahead

The following lists some of the challenges that lie ahead for hydrogen equipment providers:

- FCEV cost
- Station total capital
- Station operational costs
- Hydrogen delivery costs
- Electricity prices
- Costs of the compression/storage/dispensing subsystem, in particular
- Land lease costs
- Costs for chilling hydrogen to -40 degrees Celsius to meet the requirements of the fast-filling fueling protocol SAE International J2601 as a current technical barrier, with greater thermal efficiency cited as the specific development required
- Lack of incentives for on-site production, especially with renewable electricity
- The difference between the costs of operating stations and the revenues during low-utilization early years, which is not yet sufficiently offset. Respondents also connected long permitting times to a lack of industry-accepted listing and certification opportunities.

Hydrogen Supply Chain Market Potential

Respondents indicated that they see a fully developed FCEV market providing demand to support 20 to 100 stations developed in California each year. Companies aim for 10 to 50 percent of this market to consider themselves competitive. Respondents indicated they could either achieve this rate of production with the resources they have today or would need to expand their production capacity by as many as 15 stations per year. These companies indicated that this scale of production capacity expansion could be achieved in less than a year to as much as six years. Overall, these results seem to indicate that the equipment supplier industry as a whole may be able to support a 100-station-per-year production rate within roughly a five-year time frame.

Independent Station Operator Vignette

Companies included in the Independent Operator group are businesses whose primary or sole operation in California's hydrogen refueling network is as a hydrogen refueling network developer or operator or both (at the time of the survey distribution). These companies have a primary focus on hydrogen refueling station network development; therefore, compared to other companies that also participate in hydrogen refueling network development, independent operators' decisions for continued participation in hydrogen refueling network development may be made more independently from other competing business venture opportunities. These respondents, therefore, are not asked about their current or potential role in the broader hydrogen station supply chain.

Surveys sent to independent operators were returned with a 100 percent response rate. Not all questions were answered by all respondents. Independent operators are largely Californiacentric; individually, independent operators have up to 19 stations in operation in California and up to 12 in development. None of the companies in this group reported being involved in station development in other parts of the United States but are developing as many as seven stations in other countries. (None of these stations are yet operational.) Through these companies' operating stations, they dispense in excess of 700 metric tons of hydrogen per year. These companies are largely newer business ventures, with 5 to 12 years of experience in hydrogen-related business.

Indicators of a Profitable Hydrogen Refueling Station

Respondents indicated that daily peak-to-peak design capacity around 500 kilograms per day may be necessary to enable profitable operations. All respondents noted that their minimum requirements were representative of a station with gaseous on-site storage. These stations would require anywhere from 50 to 80 percent utilization (the ratio of hydrogen sold in a day to the theoretical maximum per the station design), with 73 percent specifically referenced by at least one respondent. Capital costs from $5,000 per kilogram to as much as $20,000 per kilogram were reported, with specific responses of $9,979 and $13,000 provided. Operations and maintenance costs would need to be between $5 and $10 per kilogram, with $5.75 specifically cited. Hydrogen procurement costs could be in the range of $8 to $10 per kilogram, with a customer-facing price at the pump as low as $8 to $12 per kilogram or as much as more than $15 per kilogram. Specific responses of $16.50 and $15.50 per kilogram were provided, which reflect prices that today's consumers encounter. The implication of considering these factors may be that some of the largest stations in California's developing network could be profitable in some cases, provided that FCEV deployment is great enough to provide the cited utilization rate. However, with many stakeholders citing a need to reduce consumer prices at the pump, cost improvements appear necessary to meet self-sufficiency and lower pump price goals simultaneously.

Additional considerations for profitability included:

- A move toward larger stations to reduce per-kilogram fixed costs and alleviate queuing in high-market areas at high-demand times.
- Greater implementation of liquid hydrogen.
- Continued support of the CARB LCFS program.
- Funding for networks of stations (8 to 10 or more per operator).
- Uncertainty in the market to spur traditional investors.

Assessing Investment Opportunities

Respondents in this group were hesitant to project the potential size of their businesses in a fully developed market, but they did provide insights on factors that inform their decision-making. Respondents indicated that under widespread FCEV adoption, the expected payback period for the development of stations would be between five and eight years. In the early hydrogen fueling market, respondents indicated an internal rate of return could be negative, but expectations could be set as high as 8 percent. In the fully realized market, 10 to 12 percent could be expected for these companies, but traditional investors could seek greater performance of 18 to 20 percent IRR.

Key performance indicators could include a viable hydrogen network (no quantification for this response was provided), the number of on-the-road FCEVs reaching 20,000 within three to five years (with an associated demand of 1,100 kilograms per day), and the value of LCFS credits for 33 percent renewable hydrogen reaching at least $3.50 per kilogram within the next five years. External market signals that could support investment at a loss or less-than-expected return included increased FCEV deployment and marketing, consistent ZEV policy support, and consistency in ZEV-supporting legislation.

Respondents agreed that ancillary services have the potential to improve the business case for hydrogen refueling stations, though respondents were split on whether their current business model depends on these additional revenue streams. Respondents defined ancillary services as including fleet vehicle fueling, car sharing, maintenance programs to support station operations across the entire network, a corporate sponsorship program, and participation in electric grid markets.

Competing Forces

Respondents largely reported that there were no opportunity costs considered in their decision to pursue hydrogen refueling network development as a business. However, existing renewable hydrogen production investments were mentioned in this context. Respondents also mostly reported that their hydrogen refueling network business growth has to account for some amount of sunken costs; past investments of up to $1.5 million were cited.

Additional Station Design and Operation Details

Respondents were largely in agreement that most station equipment components could have a lifetime around 15, and up to 20, years. Notable exceptions were nozzles with an expected lifetime of around 5 years and dispenser and point-of-sale systems, which may last as little as 8 to 10 years. Respondents agreed that stations with gaseous storage systems are viable up to capacities of 400 kilograms per day, and that liquid stations are possible from 350 to 4,000 or more kilograms per day. Respondents saw the difference in per-kilogram compression costs between liquid and gaseous stations as relatively small; compression costs represented 11 percent to 15 percent of costs on gaseous stations and up to 10 percent on liquid (though some respondents indicated no compression costs for liquid).

The reported advantages of stations incorporating liquid hydrogen storage include:

- Greater opportunity for self-sufficiency in the near term.
- Economics and technology being more favorable for liquid, with greater transportation volumes, reduced logistics costs, and greater potential throughput per station.
- Liquid storage requiring less space than gaseous storage (and potentially less than even gasoline) per kilogram of capacity.

- Electric pumps in liquid stations consuming up to 10 times less electric power than gaseous compressors.

Challenges Ahead

For operating stations, respondents reported that the total equipment package cost represents a capital barrier. Costs are as much as $2.3 million per station, and respondents expressed a desire for costs less than $1.3 million. Respondents likewise reported total operational expenditures as a barrier, with costs as high as $200,000 per year and a target of less than $150,000 per year. Potentially related to the total operations costs, fuel procurement costs in particular were highlighted as $7 to $9 per kilogram and a target of $4 to $6 per kilogram. Finally, respondents mentioned electricity demand charges for station operation as a barrier, with no quantification of the current or necessary cost for profitability.

Reported technical barriers to profitable business included current logistics strategies and the lack of compressors/vaporizers onboard hydrogen delivery trucks, which could presumably help reduce at-station costs. Nozzle costs and freeze-locking (a situation where the locking mechanism on a hydrogen fueling nozzle becomes temporarily locked in the closed and connected position because the very cold delivery temperature of hydrogen can cause moisture in the air to freeze around the mechanism) were also mentioned. Finally, respondents listed costs of intermittent power consumption and the related demand charges as technical barriers, pointing to the need for new station operational strategies.

When asked about policy barriers, respondents indicated that consistency and certainty of public sector support needed to be maintained. In addition, some aspects of past grant funding programs were cited as potentially limiting. These aspects included strict location requirements, reimbursement of expenditures as opposed to grants that provide funds upfront, and losses of grant funds due to contingencies and changes of station development plans as a station is engineered and constructed.

The only permitting and development barrier that was cited was a need for updating the setback requirements (specifically for liquid stations) in NFPA 2, which multiple respondents cited.

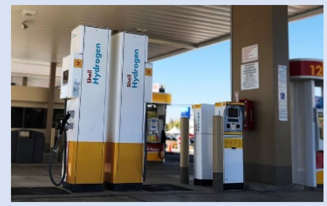
Additional factors that respondents mentioned in the survey included:

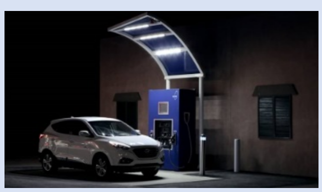
- Available space at a chosen host site and the site owner's buy-in. (Owners may be excited about new technology but want no effect on existing business at the location.)
- Finding funders and suppliers that also buy into the vision of a statewide hydrogen refueling network.
- Risk aversion in traditional markets.
- Inquiries and interest from cities and companies outside major identified markets.

APPENDIX D: ARFVTP-Funded Stations

Table D-1 shows 38 ARFVTP-funded open retail stations, of which 7 became open retail in 2018. All photos were taken by ARFVTP staff with the exceptions, as noted.

Table D-1: 38 ARFVTP-Funded Open Retail Stations

ARFVTP-Funded Stations			
	 Photo Credit: Air Liquide		 Photo Credit: California Fuel Cell Partnership
Name	Anaheim	Campbell	Citrus Heights
Address	3731 East La Palma Avenue	2855 Winchester Boulevard	6141 Greenback Lane
Open Retail Date	11/29/2016	6/9/2016	12/18/2018
Solicitation	PON-12-606	PON-13-607	GFO-15-605

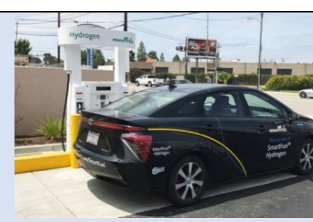
	 Photo Credit: FirstElement Fuel		
Name	Coalinga	Costa Mesa	Del Mar (San Diego)
Address	24505 W. Dorris Avenue	2050 Harbor Boulevard	3060 Carmel Valley Road
Open Retail Date	12/11/2015	1/21/2016	12/2/2016
Solicitation	PON-13-607	PON-13-607	PON-13-607

Source: California Energy Commission, photo credit: California Energy Commission unless otherwise stated

ARFVTP-Funded Stations

		 Photo Credit: Linde	 Photo Credit: Air Products and Chemicals, Inc.
Name	Diamond Bar	Emeryville	Fairfax (Los Angeles)
Address	21865 East Copley Drive	1172 45th Street	7751 Beverly Boulevard
Open Retail Date	8/18/2015	11/19/2018	5/2/2016
Solicitation	PON-09-608	PON-13-607	PON-09-608

	 Photo Credit: FirstElement Fuel		
Name	Fremont	Hayward	Hollywood (Los Angeles)
Address	41700 Grimmer Boulevard	391 West A Street	5700 Hollywood Boulevard
Open Retail Date	9/7/2017	4/27/2016	11/10/2016
Solicitation	PON-13-607	PON-13-607	PON-13-607

		 Photo Credit: FirstElement Fuel	 Photo Credit: Air Products and Chemicals, Inc.
Name	La Cañada Flintridge	Lake Forest	Lawndale
Address	550 Foothill Boulevard	20731 Lake Forest Drive	15606 Inglewood Avenue
Open Retail Date	1/25/2016	3/18/2016	6/22/2017
Solicitation	PON-13-607	PON-13-607	PON-09-608

ARFVTP-Funded Stations

	 Photo Credit: Air Liquide		 Photo Credit: FirstElement Fuel
Name	LAX (Los Angeles)	Long Beach	Mill Valley
Address	10400 Aviation Boulevard	3401 Long Beach Boulevard	570 Redwood Highway
Open Retail Date	12/21/2018	2/22/2016	6/16/2016
Solicitation	SCAQMD Contract	PON-13-607	PON-13-607
	 Photo Credit: Linde	 Photo Credit: Ontario Station	 Photo Credit: Air Liquide
Name	Mountain View	Ontario	Palo Alto
Address	830 Leong Drive	1850 E. Holt Boulevard	3601 El Camino Real
Open Retail Date	2/28/2018	4/24/2018	12/20/2018
Solicitation	PON-12-606	PON-13-607	PON-13-607

Source: California Energy Commission, photo credit: California Energy Commission unless otherwise stated

ARFVTP-Funded Stations

	 Photo Credit: FirstElement Fuel	 Photo Credit: ITM Power	 Photo Credit: FirstElement Fuel
Name	Playa Del Rey (Los Angeles)	Riverside	San Jose
Address	8126 Lincoln Boulevard	8095 Lincoln Avenue	2101 North 1st Street
Open Retail Date	8/18/2016	3/8/2017	1/15/2016
Solicitation	PON-13-607	PON-13-607	PON-13-607

		 Photo Credit: California Fuel Cell Partnership	 Photo Credit: FirstElement Fuel
Name	San Juan Capistrano	San Ramon	Santa Barbara
Address	26572 Junipero Serra Road	4475 Norris Canyon Road	150 South La Cumbre Road
Open Retail Date	12/23/2015	7/26/2017	4/9/2016
Solicitation	PON-09-608	PON-13-607	PON-13-607

Source: California Energy Commission, photo credit: California Energy Commission unless otherwise stated

ARFVTP-Funded Stations

			 Photo Credit: FirstElement Fuel
Name	Santa Monica	Saratoga	South Pasadena
Address	1819 Cloverfield Boulevard	12600 Saratoga Avenue	1200 Fair Oaks Avenue
Open Retail Date	2/1/2016	3/14/2016	4/10/2017
Solicitation	PON-09-608	PON-13-607	PON-13-607

			 Photo Credit: SCAQMD
Name	South San Francisco	Thousand Oaks	Torrance
Address	248 South Airport Boulevard	3102 Thousand Oaks Boulevard	2051 West 190th Street
Open Retail Date	2/12/2016	3/30/2018	8/18/2017
Solicitation	PON-13-607	PON-13-607	SCAQMD Contract

Source: California Energy Commission, photo credit: California Energy Commission unless otherwise stated

ARFVTP-Funded Stations

	 Photo Credit: FirstElement Fuel		
Name	Truckee	UC Irvine	West LA (Los Angeles)
Address	12105 Donner Pass Road	19172 Jamboree Road	11261 Santa Monica Boulevard
Open Retail Date	6/17/2016	11/12/2015	10/29/2015
Solicitation	PON-13-607	PON-09-608	PON-09-608

		 Photo Credit: Air Products and Chemicals, Inc.	
Name	West Sacramento	Woodland Hills	
Address	1515 South River Road	5314 Topanga Canyon Road	
Open Retail Date	7/7/2015	10/5/2016	
Solicitation	PON-09-608	PON-12-606	

Source: California Energy Commission, photo credit: California Energy Commission unless otherwise stated

Table D-2 lists the locations of 26 ARFVTP-funded planned stations by county. These stations are in various development phases: planning, permitting, or under construction. Also provided is the Energy Commission solicitation number under which the station received funding.

Table D-2: 26 ARFVTP-Funded Planned Stations

Address	Solicitation
1250 University Avenue, Berkeley, CA 94702	GFO-15-605
9988 Wilshire Boulevard, Beverly Hills, CA 90210	GFO-15-605
145 West Verdugo Avenue, Burbank, CA 91510	SCAQMD Contract
337 East Hamilton Avenue, Campbell, CA 95008	GFO-15-605
12600 East End Avenue, Chino, CA 91710	PON-12-606
18480 Brookhurst Street, Fountain Valley, CA 92708	GFO-15-605
5333 University Drive, Irvine, CA 92612	GFO-15-605
5151 State University Drive, Los Angeles, CA 90032	ARFVTP O&M
15544 San Fernando Mission Boulevard, Mission Hills, CA 91345	GFO-15-605
350 Grand Avenue, Oakland, CA 94610	GFO-15-605
28103 Hawthorne Boulevard, Rancho Palos Verdes, CA 90275	PON-09-608
503 Whipple Avenue, Redwood City, CA 94063	GFO-15-605
3510 Fair Oaks Boulevard, Sacramento, CA 95864	GFO-15-605
5494 Mission Center Road, San Diego, CA 92108	GFO-15-605
1201 Harrison Street, San Francisco, CA 94103	GFO-15-605
3550 Mission Street, San Francisco, CA 94110	GFO-15-605
551 Third Street, San Francisco, CA 94107	GFO-15-605
24551 Lyons Avenue, Santa Clarita, CA 91321	PON-09-608
1866 Lincoln Boulevard, Santa Monica, CA 90405	GFO-15-605
12754 State Hwy 33, Santa Nella, CA 95322	GFO-15-605
14478 Ventura Boulevard, Sherman Oaks, CA 91423	GFO-15-605
3780 Cahuenga Boulevard, Studio City, CA 91604	GFO-15-605
1296 Sunnyvale Saratoga Road, Sunnyvale, CA 94087	GFO-15-605
2900 N Main Street, Walnut Creek, CA 94597	GFO-15-605
17287 Skyline Boulevard, Woodside, CA 94062	PON-13-607
Mobile Refueler	PON-13-607

Source: California Energy Commission

APPENDIX E:
Hydrogen at Scale Cooperative Research and Development Agreements

In August 2017, the National Renewable Energy Laboratory (NREL) released a Cooperative Research and Development (CRADA) call to solicit projects supporting H2@Scale objectives.[57] U.S. DOE's Fuel Cell Technologies Office sought to multiply the effect of its funding and increase industrial and stakeholder participation in the advancement of H2@Scale by contributing nearly $6 million toward qualified projects. U.S. DOE approved two projects in which the ARFVTP will participate, summarized below.

Project #1—Hydrogen Safety Panel (HSP) Evaluation of Hydrogen Facilities

Demonstrated safety in the production, distribution, dispensing, and use of hydrogen is critical to the successful implementation of hydrogen refueling infrastructure and the widespread use of fuel cell technologies. In this project, Pacific Northwest National Laboratory (PPNL), operated by Battelle Memorial Institute, will collaborate with the ARFVTP to activate safety reviews from the PNNL Hydrogen Safety Panel (HSP), a multidisciplinary team of engineers, scientists, code officials, safety professionals, equipment providers, and testing and certification experts.

This three-year project includes an HSP review of state-funded hydrogen projects, including hydrogen safety plans proposed as part of solicitation applications for hydrogen refueling stations and hydrogen production plants.[58] The PNNL HSP will provide feedback on early designs from a safety viewpoint (which differs from previous solicitations in which the HSP reviewed completed station designs) and evaluate any safety incident or issue that may pose a safety threat as reported by grant recipients. The PNNL HSP will also visit sites to examine the hydrogen infrastructure funded by ARFVTP. U.S. DOE agreed to contribute $540,000 in match to the $60,000 provided from ARFVTP to bring the total project budget to $600,000.

Project #2—California Hydrogen Infrastructure Research Consortium

The California Energy Commission, in partnership with CARB, the South Coast Air Quality Management District (SCAQMD), and the Governor's Office of Business and Economic Development (GO-Biz), submitted a proposal to form the California Hydrogen Infrastructure Research Consortium with NREL. The ARFVTP is providing $100,000 to the project, matched by

57 The H2@Scale CRADA Call is described at https://www.nrel.gov/hydrogen/h2-at-scale-crada-call.html.

58 The Energy Commission encourages developers to use the HSP's *Safety Planning for Hydrogen and Fuel Cell Projects* when preparing hydrogen safety plans. Available at https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-November2017_0.pdf.

CARB and SCAQMD, while GO-Biz is providing in-kind resources, and U.S. DOE is contributing \$540,000.

The tasks of the consortium project include data analyses to identify trends in hydrogen refueling station usage and performance, and technology validation to inform decision-making regarding infrastructure technical requirements. Tasks also include evaluation of energy system integration strategies in which hydrogen can provide energy storage to the grid and otherwise curtailed renewable energy can be a source for renewable hydrogen.

The project objective is to have NREL and other H2@Scale national laboratory experts address near-term challenges for California hydrogen infrastructure development, deployment, and operation. The consortium will balance near-term research needs with accelerating earlier-stage research into the market.

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